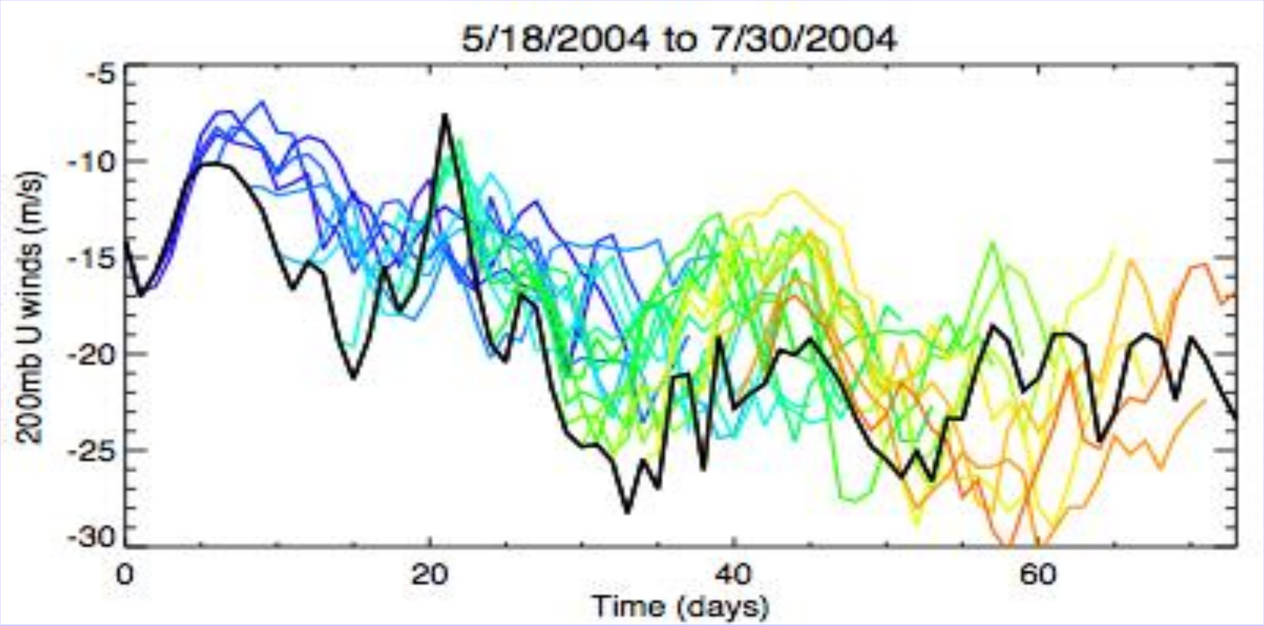
Some recent thoughts on Intraseasonal Variability



Serial forecasts of ISO

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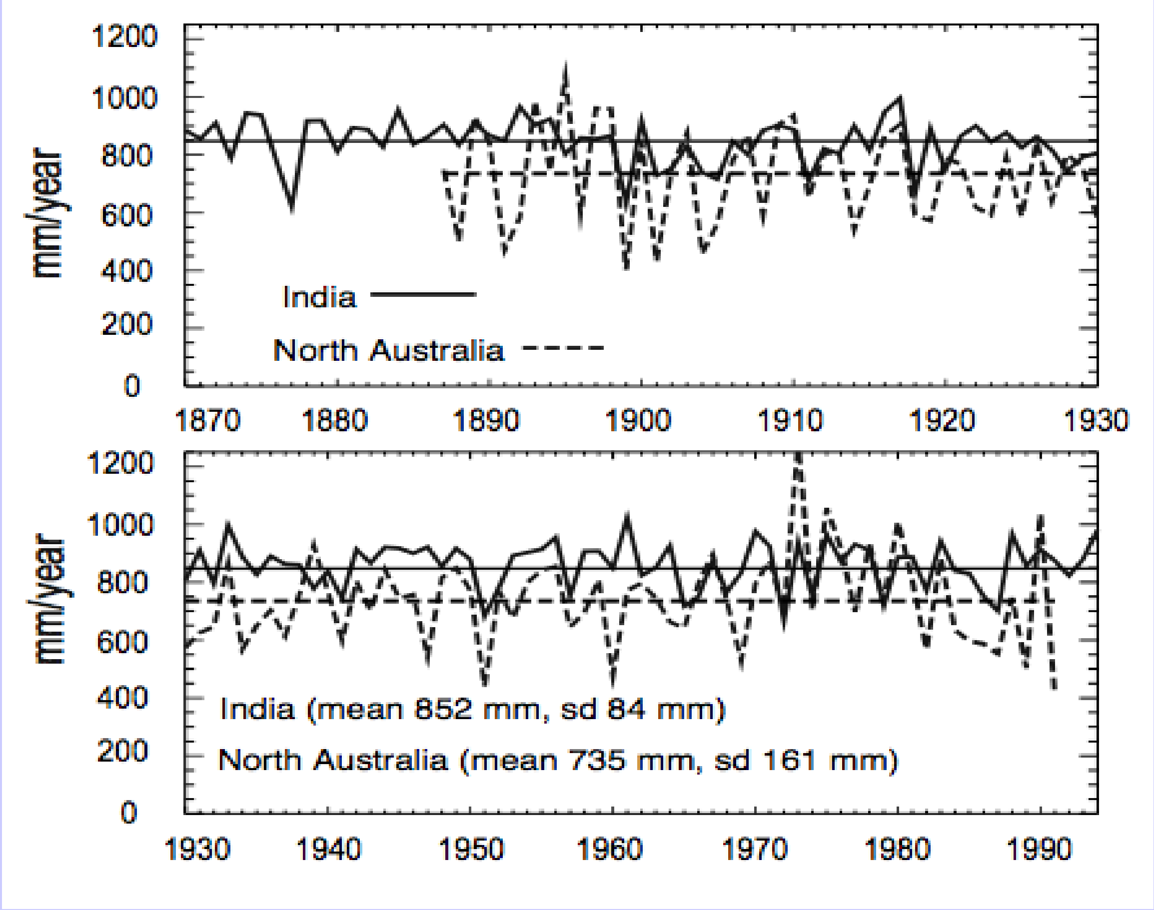
Intraseasonal Variability

- On times scales less than annual, most variability is in the intraseasonal band
- Except for ENSO, interannual variability of the tropical phenomena generally small
- Intraseasonal variability (ISO) has many peculiar aspects:
  - It is difficult to model numerically
  - It possesses predictability (empirical>>numerical)
  - It has maximum variance in the Indian Ocean where it seems to form (reform)
  - It possess propagation/growth periods that slower/longer than probable.
- Today I hope to make some suggestions of why these peculiarities exist

Seasonal forecasts

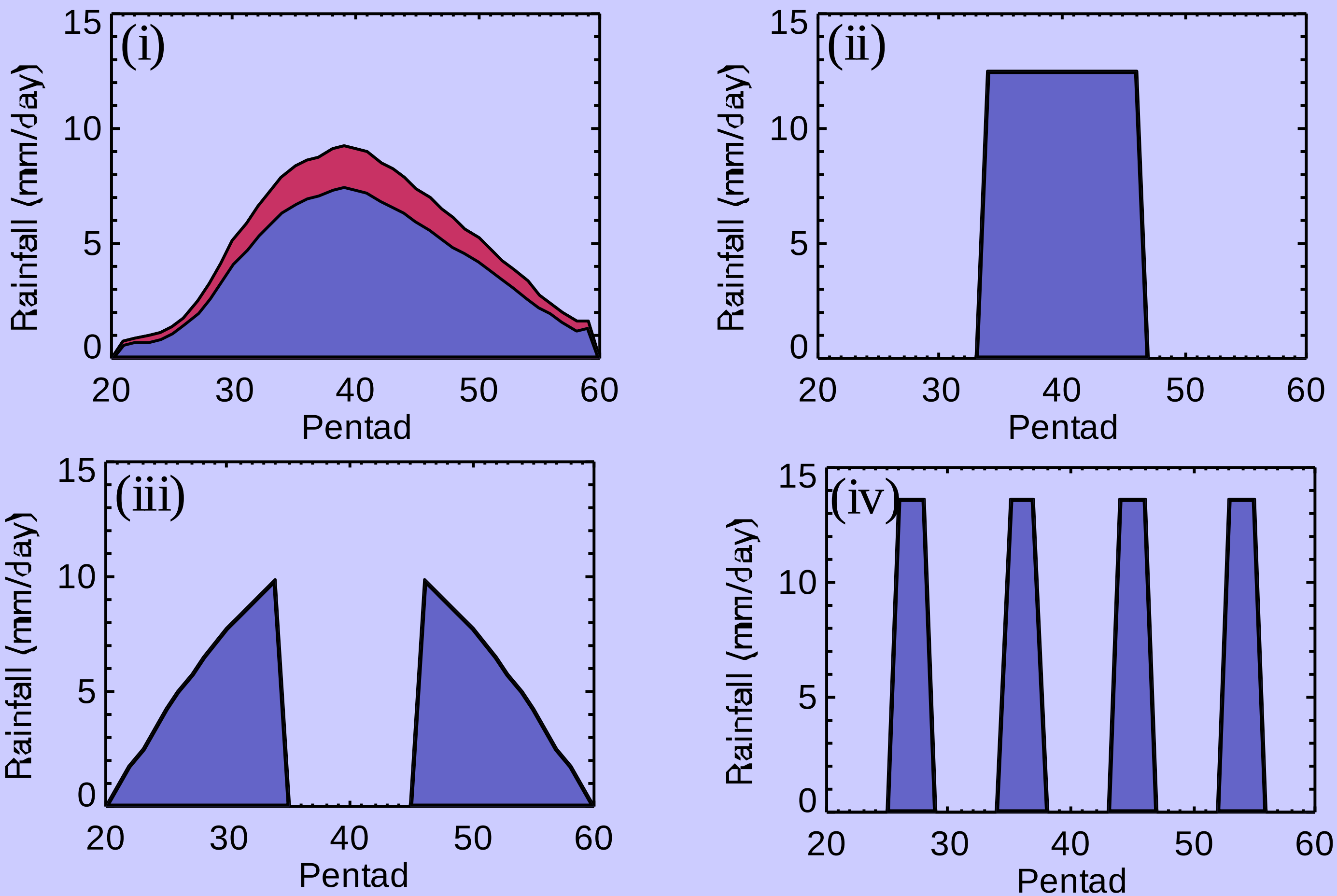
- Interest in ISO came from trying to understand the rationale of monsoon seasonal forecasts
- For the last 100 years, emphasis has been on the forecasting of monsoon interannual variability of the gross-scale monsoon
- How useful are such forecasts? Even if they were perfect?

Interannual variability of All-India rainfall is relatively small, oscillating between marginally wet and dry years with occasional extreme (e.g., 2002, 2009)



Time series of Indian and North Australian rainfall

What does <u>perfect</u> seasonal forecast say about when rainfall occurs during the season (say -20%)?



Reduce seasonal rainfall by -20%

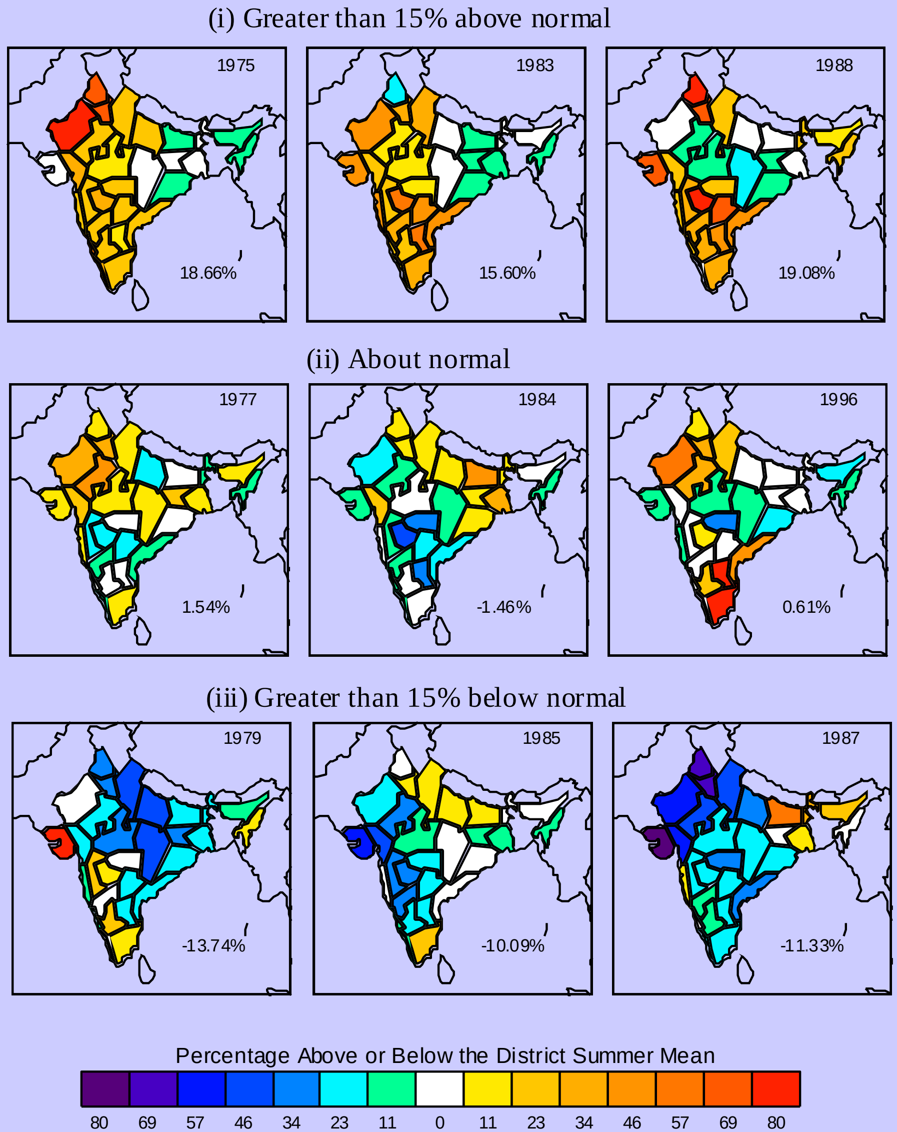
How can you use this forecast for planning?

Does it say where anomalous rainfall will occur?

>15%

normal

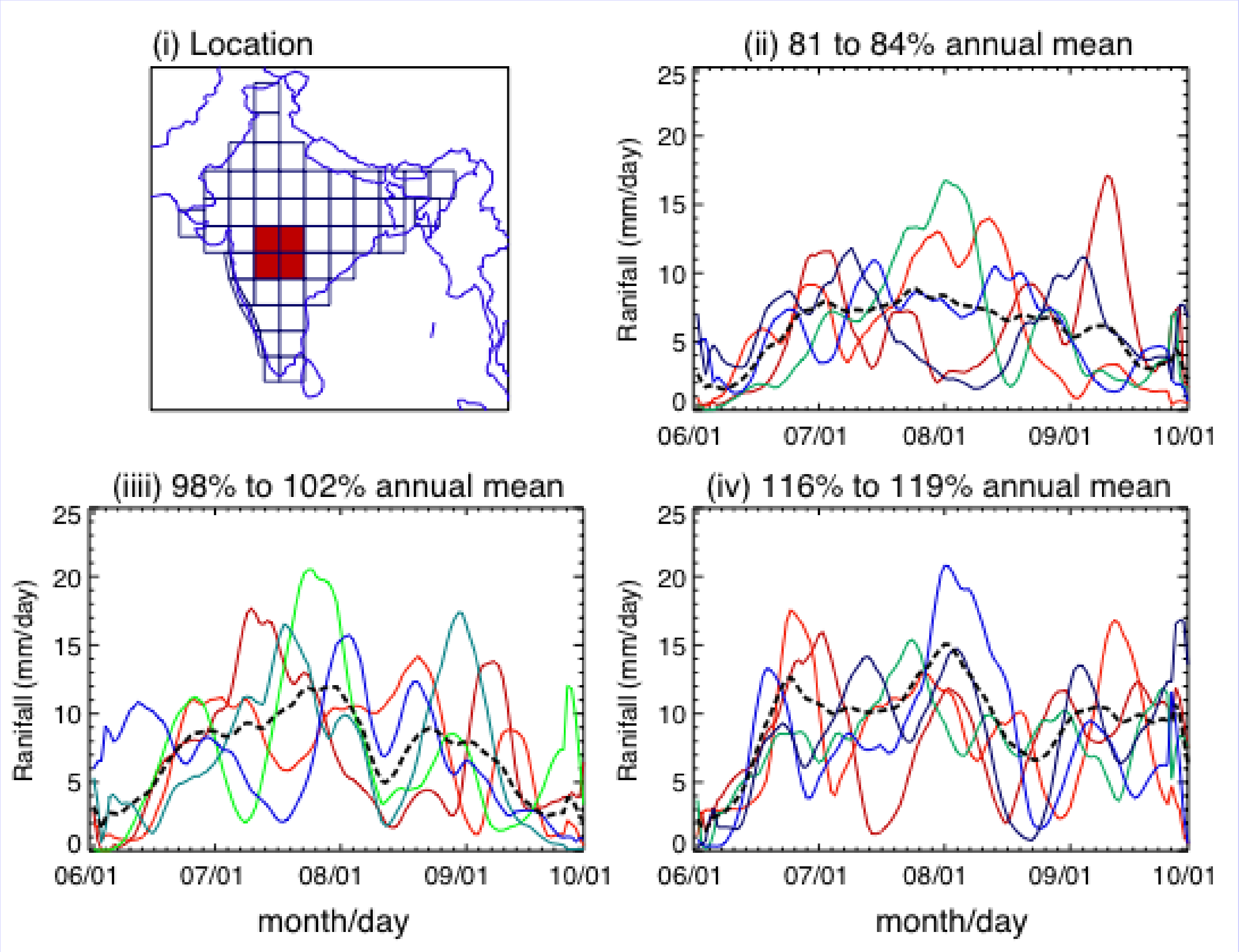
<15%



Even if the summer rainfall were forecast perfectly, there is little skill in forecasting rainfall in any one district.

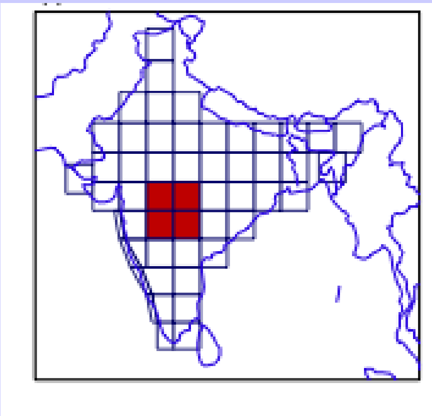
In extreme seasons (even if they were forecast) there would only be a tilt towards anomalously wet or dry but far from certainty

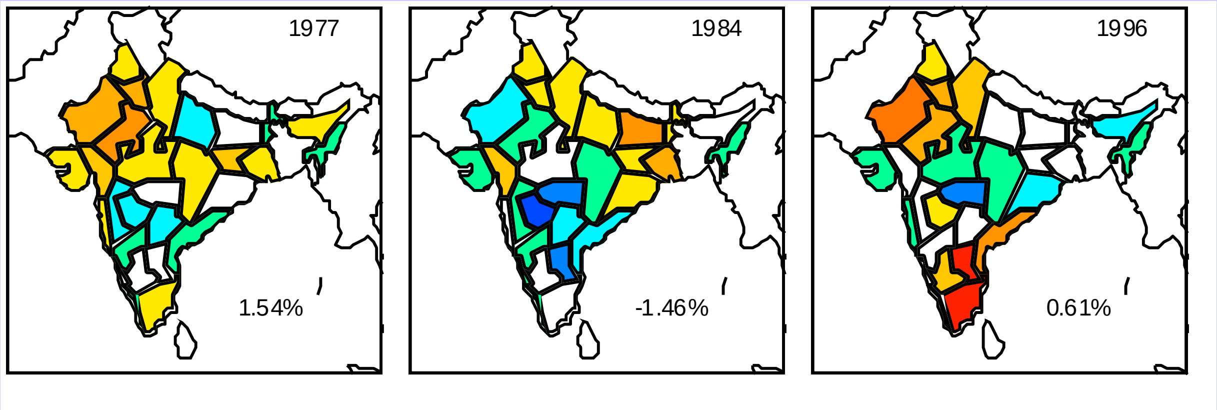
In any one location, does the perfect seasonal forecast indicate when rainfall will occur? Clear evidence of ISO!

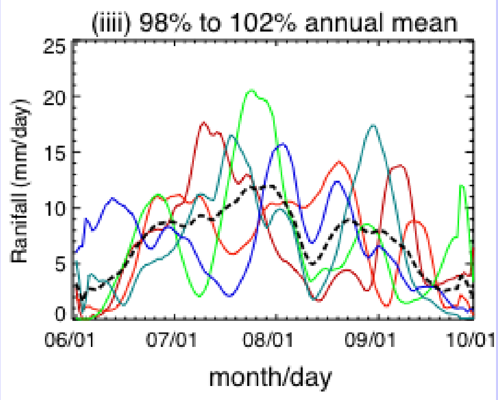


But standard deviation of mean rainfall fairly small so that most seasons close to "normal"

So, how much predictability will a perfect forecast of the mean India rainfall give to the poor rain-fed (non-irrigated) regions of Central India?

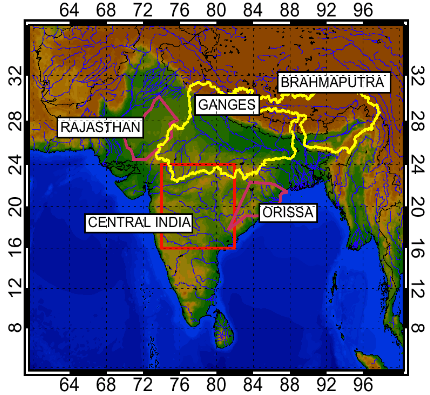


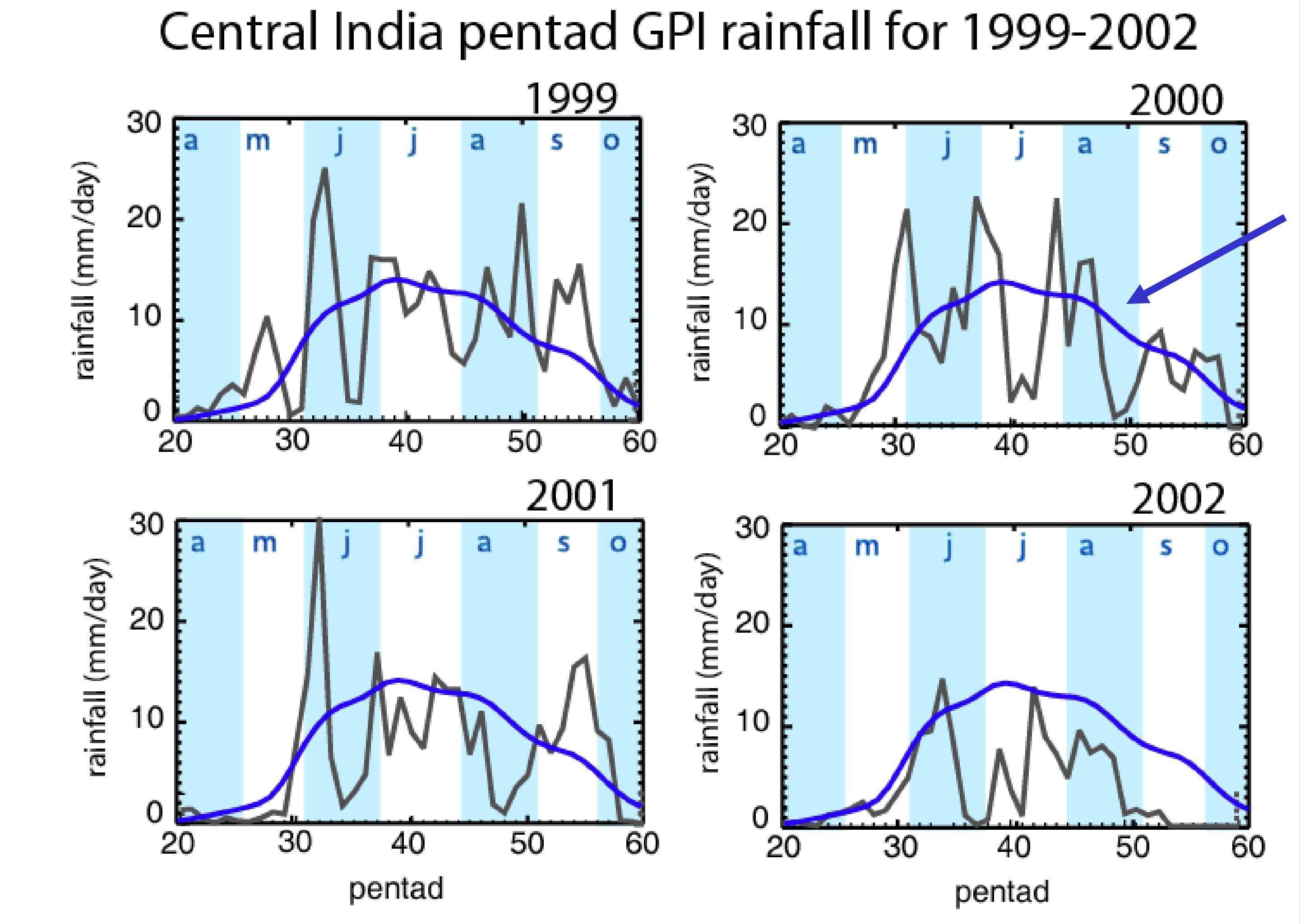




A perfect forecasts of mean rainfall provides minimal skill of quantity or timing of regional rainfall!

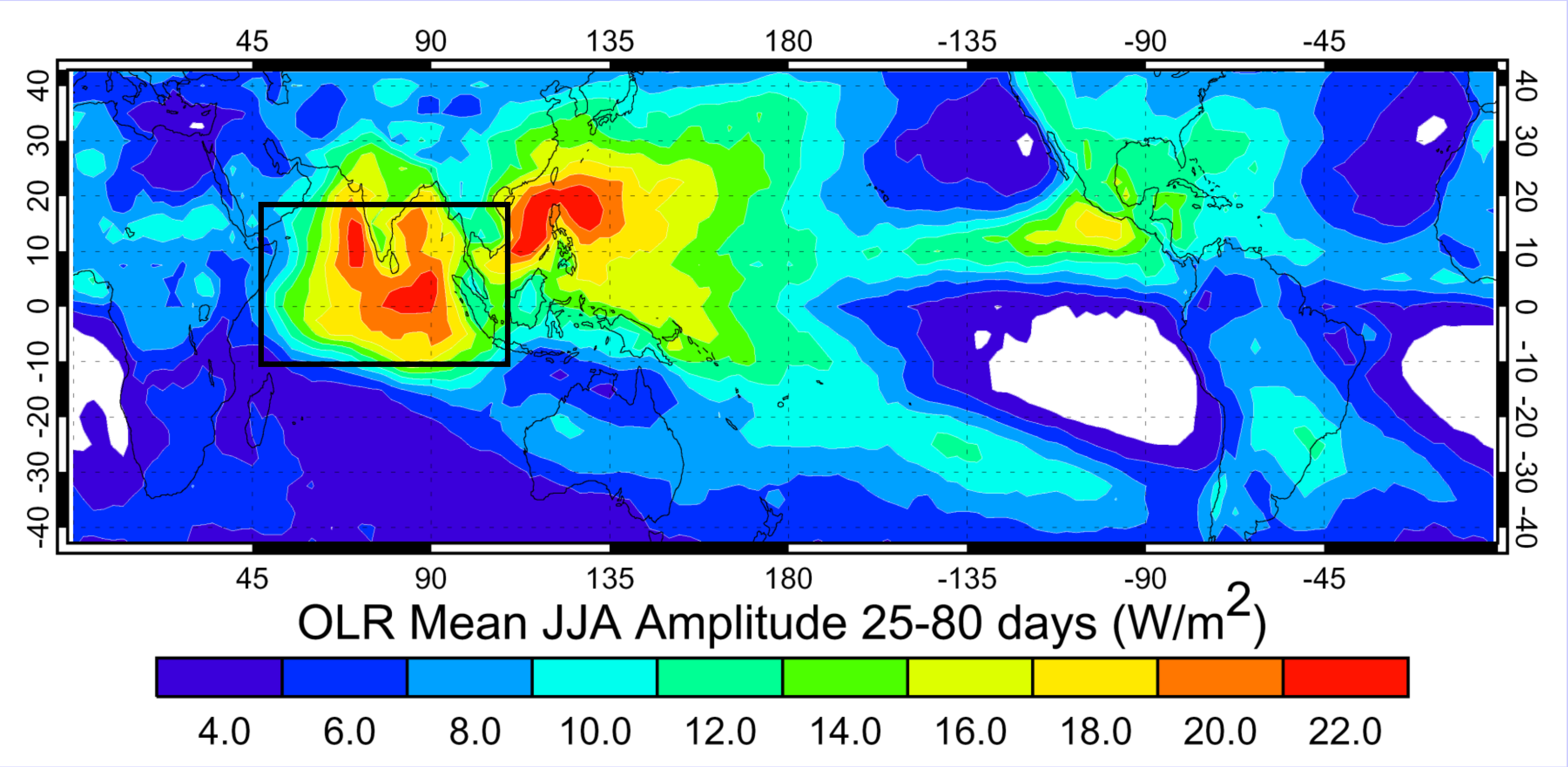
ISO rainfall accounts for the largest oscillations on all time scales



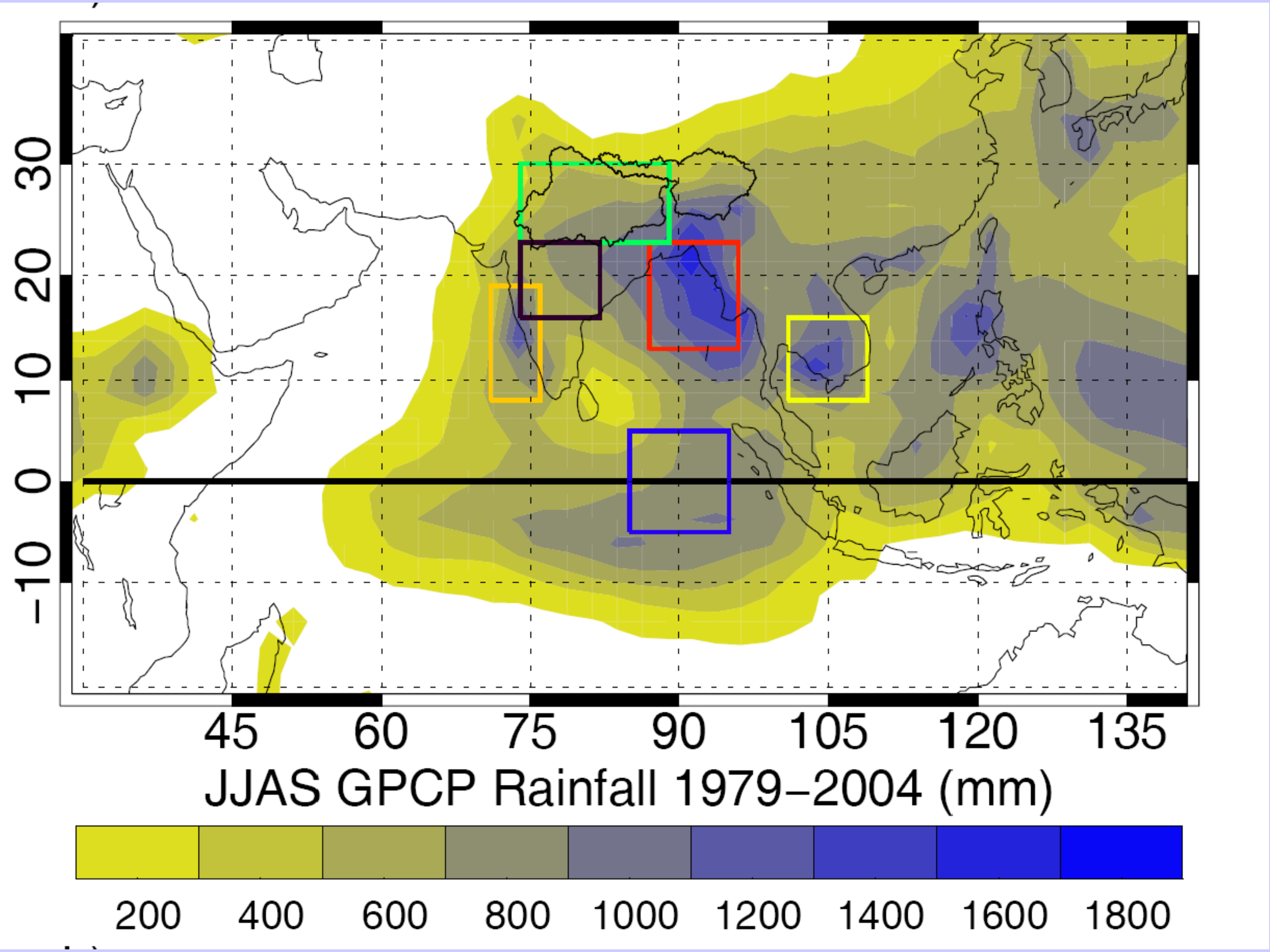


Long-term climatology

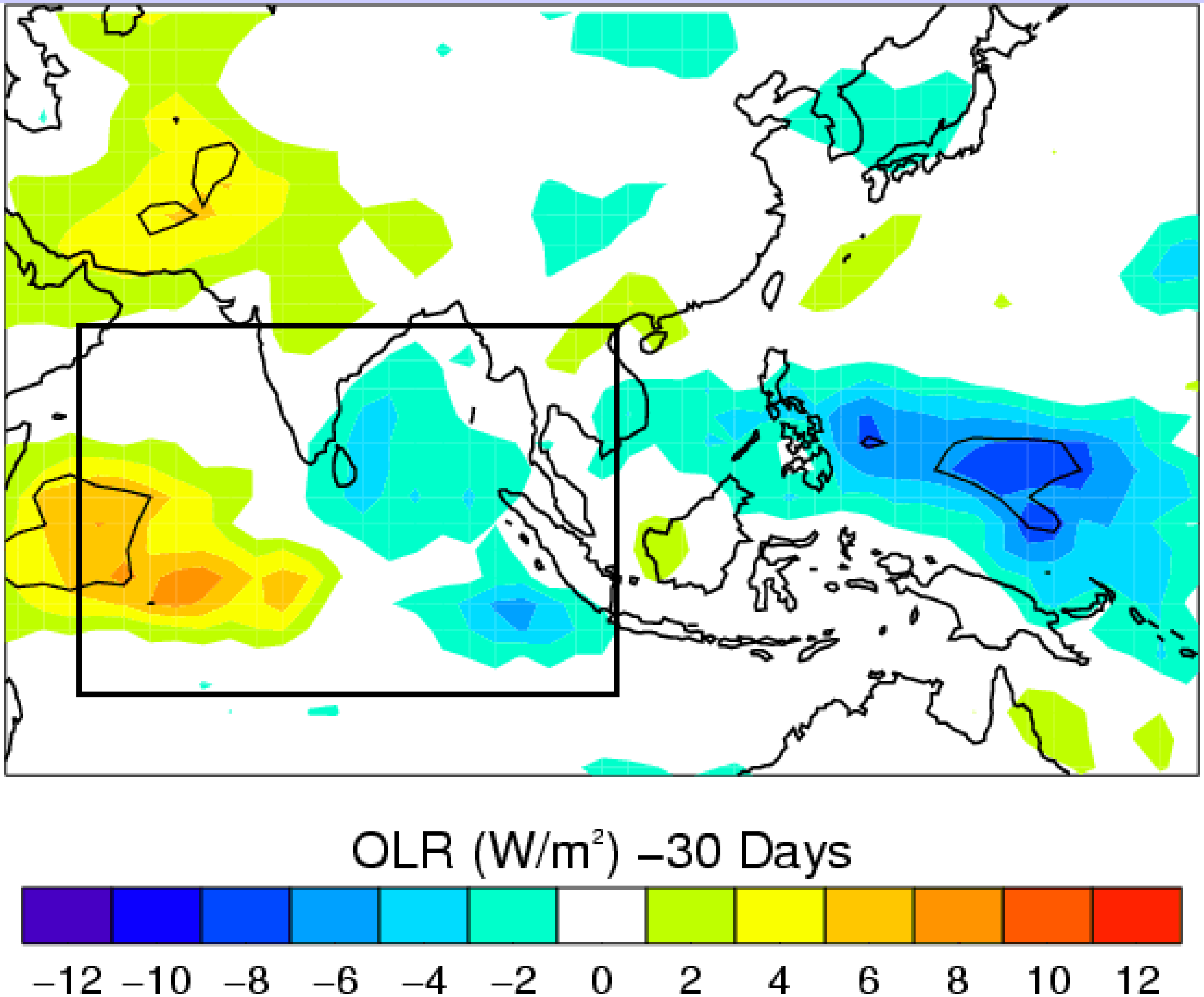
Summer Intraseasonal variability_



Summer Monsoon Rainfall

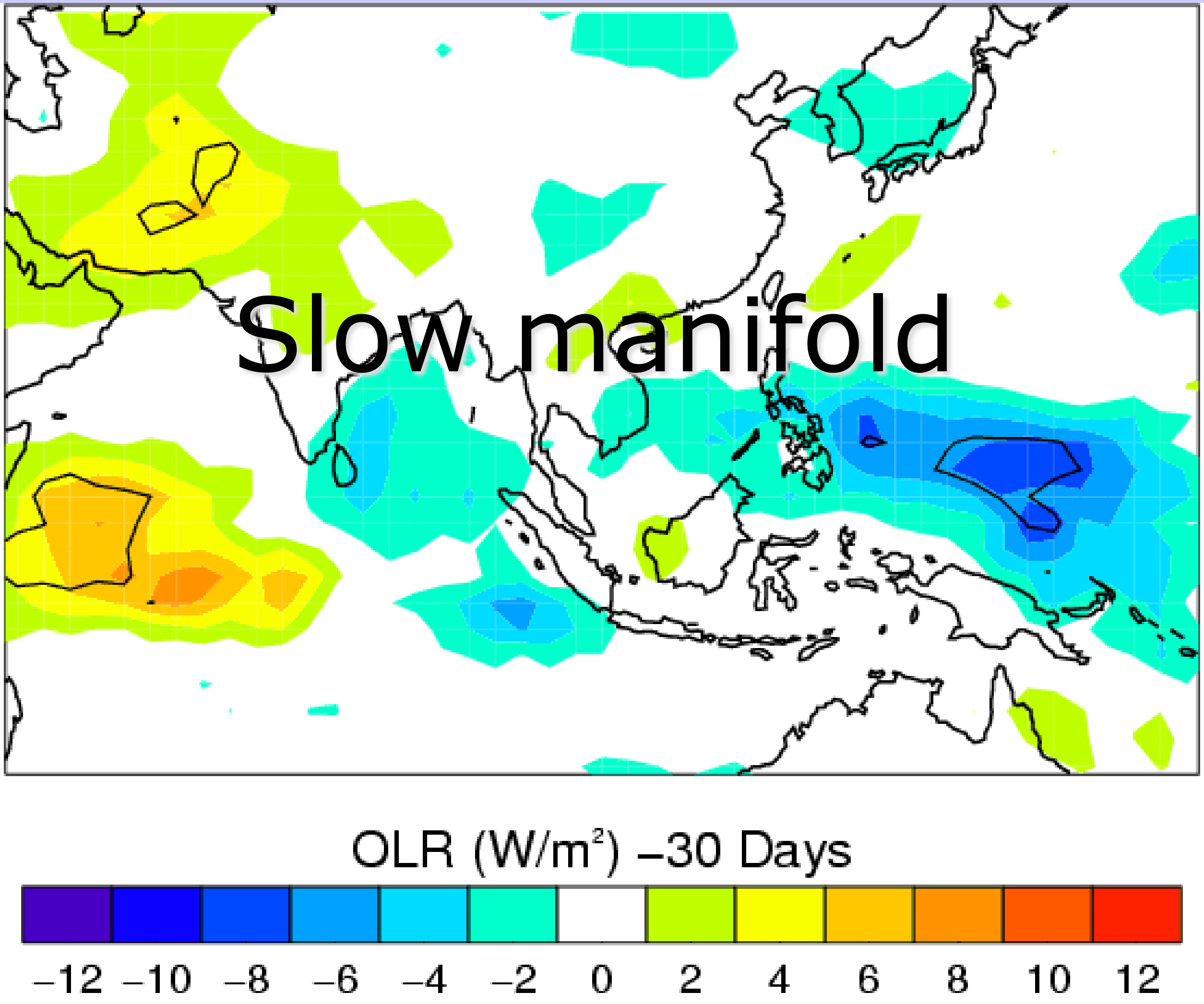


OLR Composites: 25-80 days variability



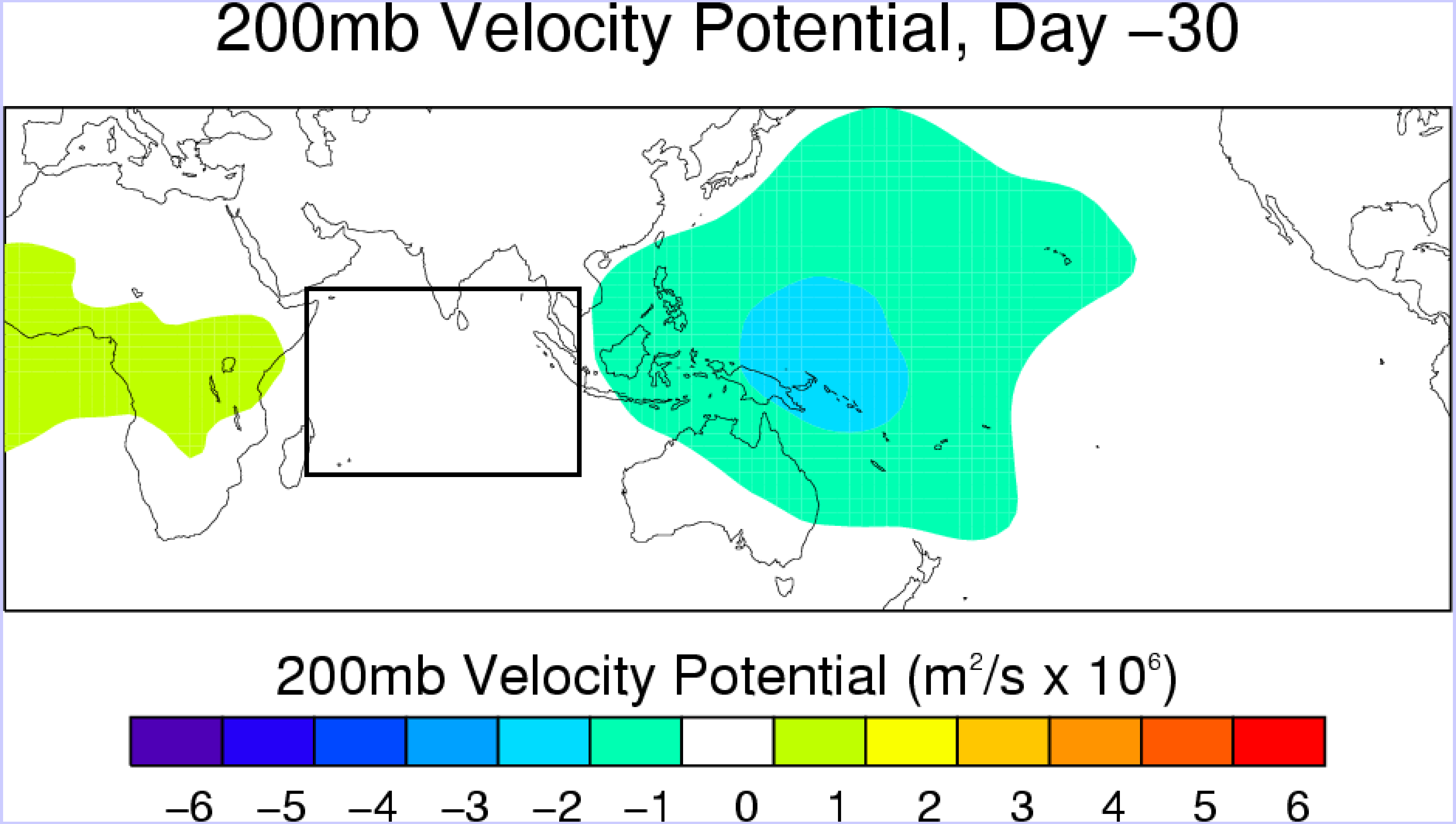
Active phases of the monsoon commence near the equator and propagate northward (and southward) across South Asia.

ISO defines a SLOW MANIFOLD of convection

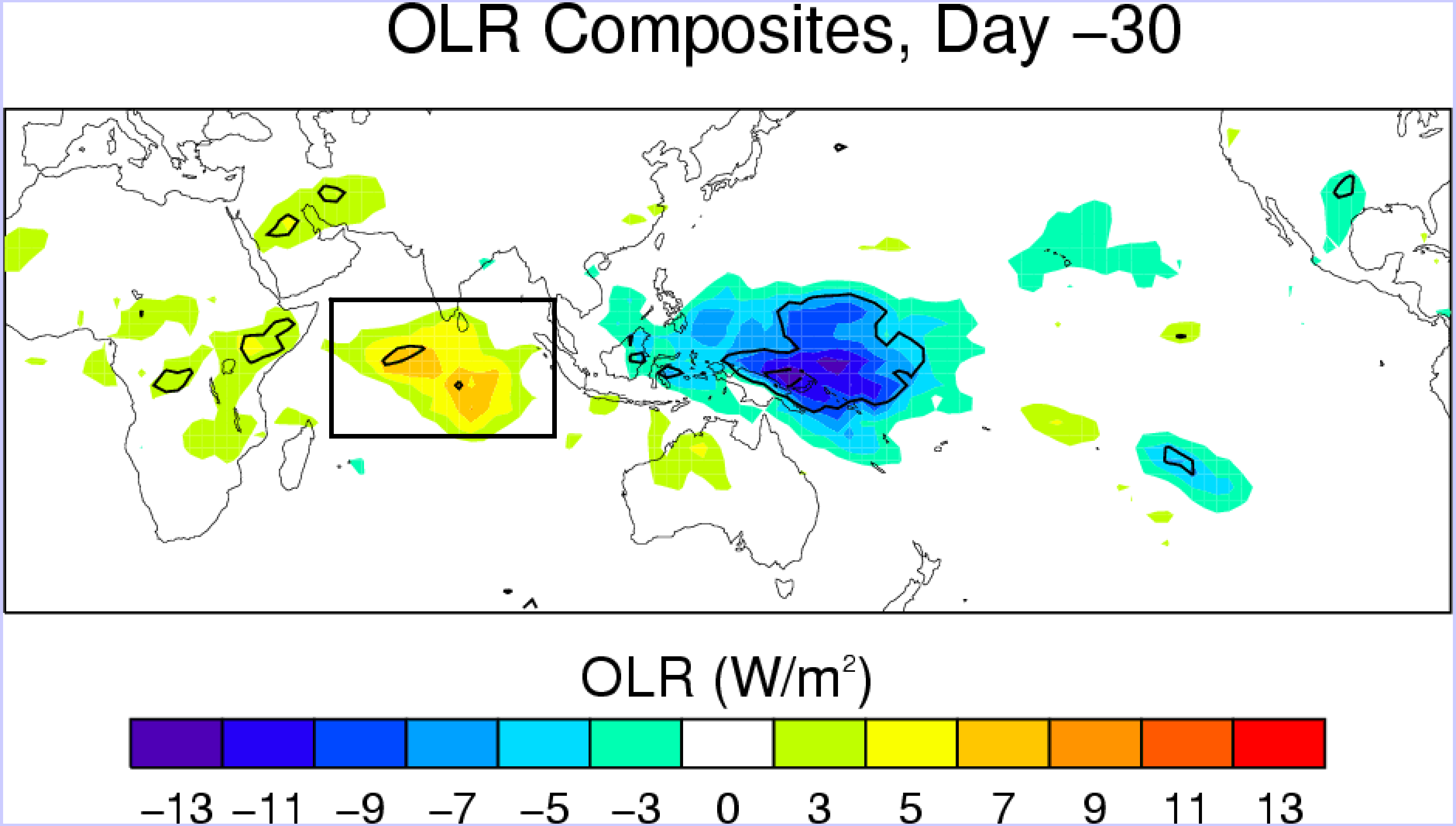


Can we utilize this strong and repeatable signal to design empirical prediction schemes or statistically rendered models?

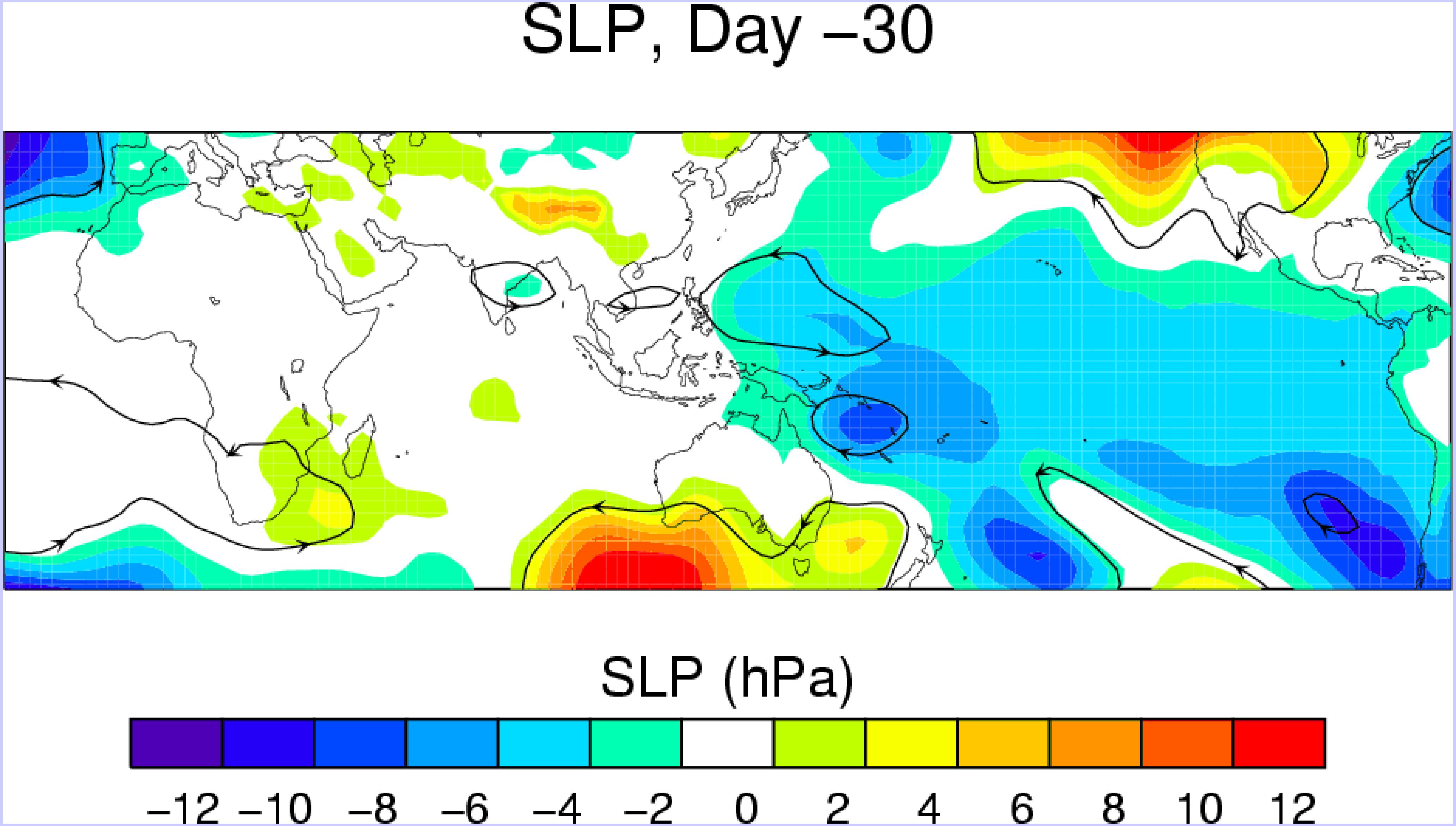
Velocity Potential 200mb: Winter



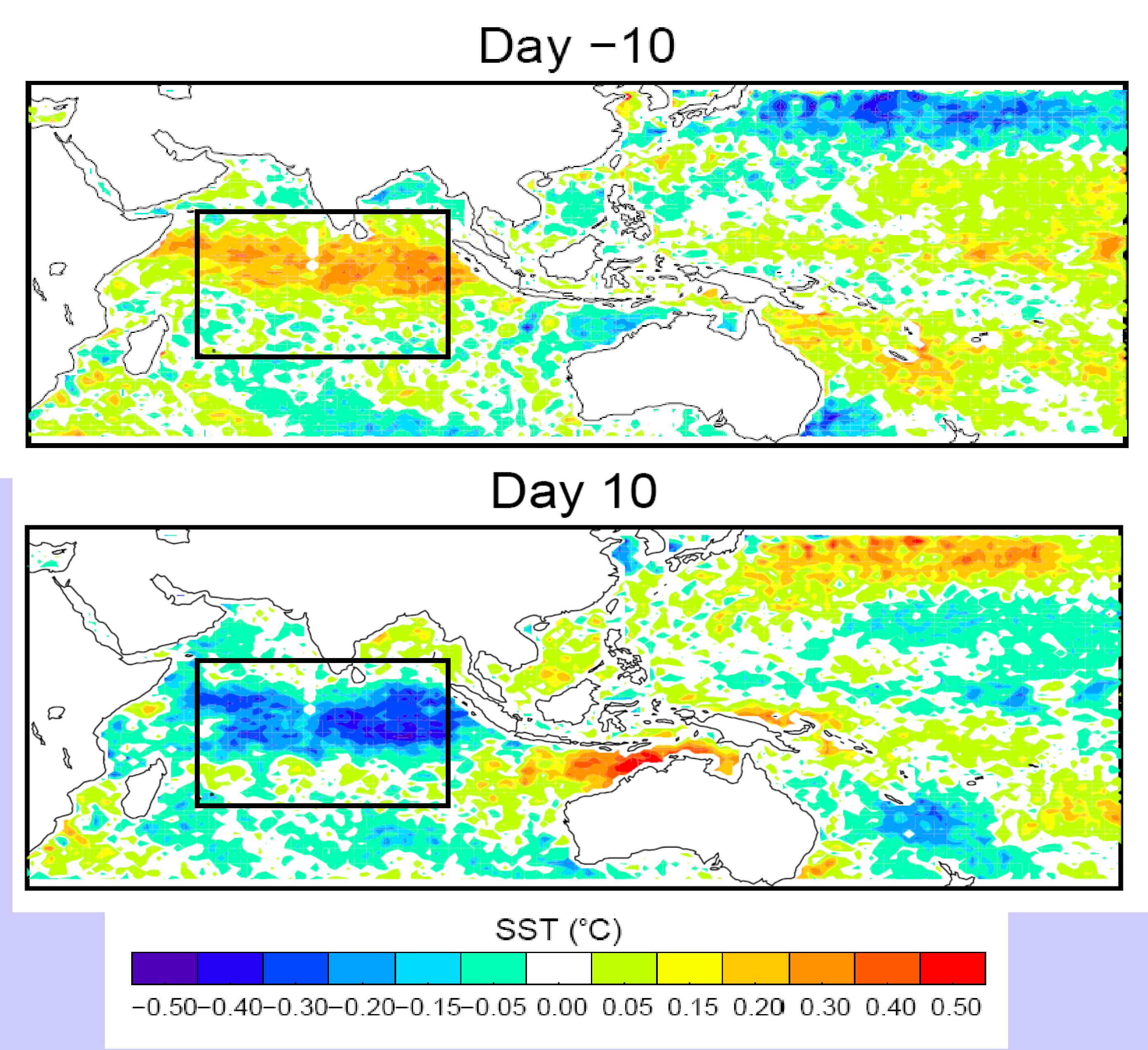
OLR Composites: Winter



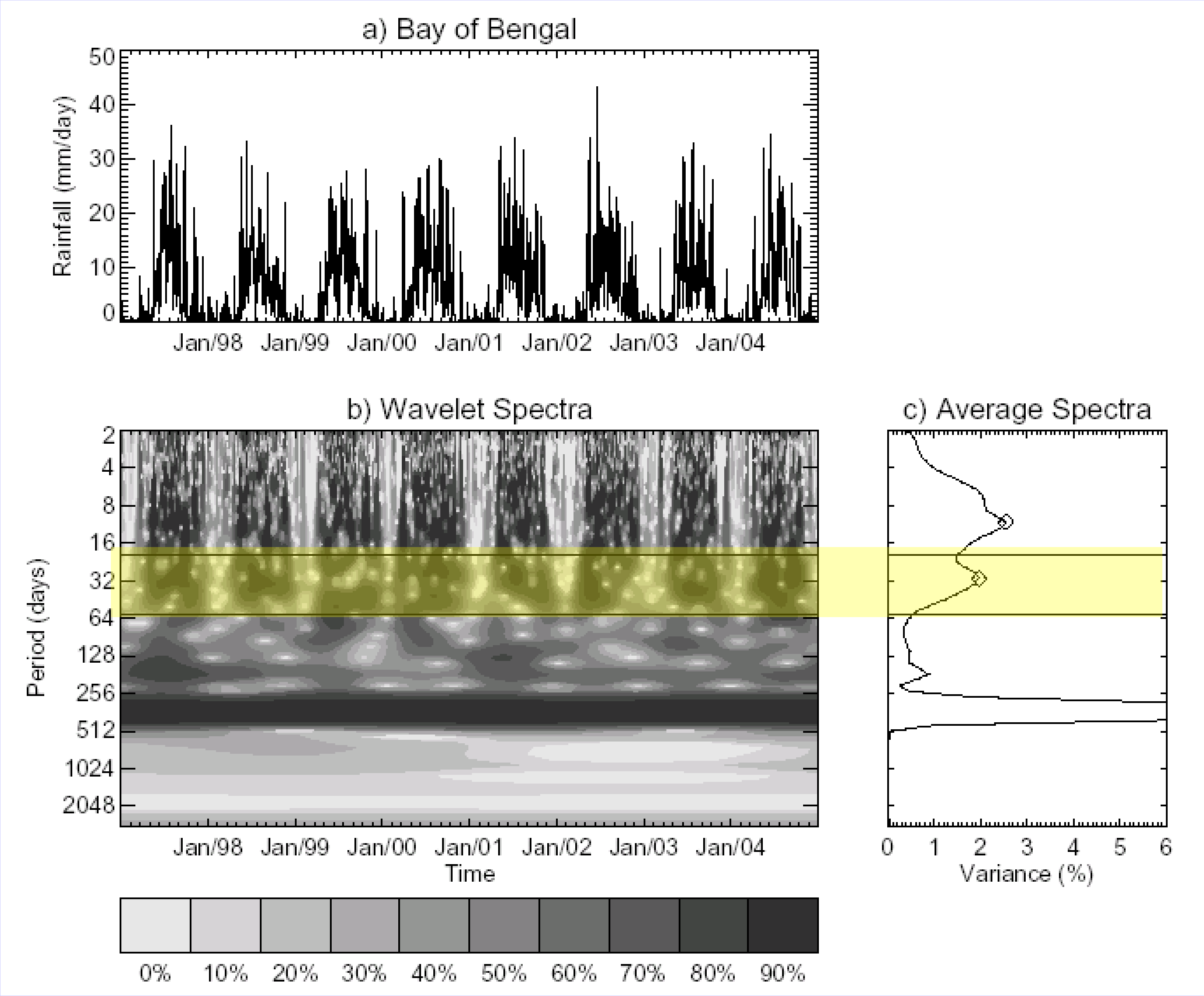
Sea Level Pressure: Winter



Sea Surface Temperature

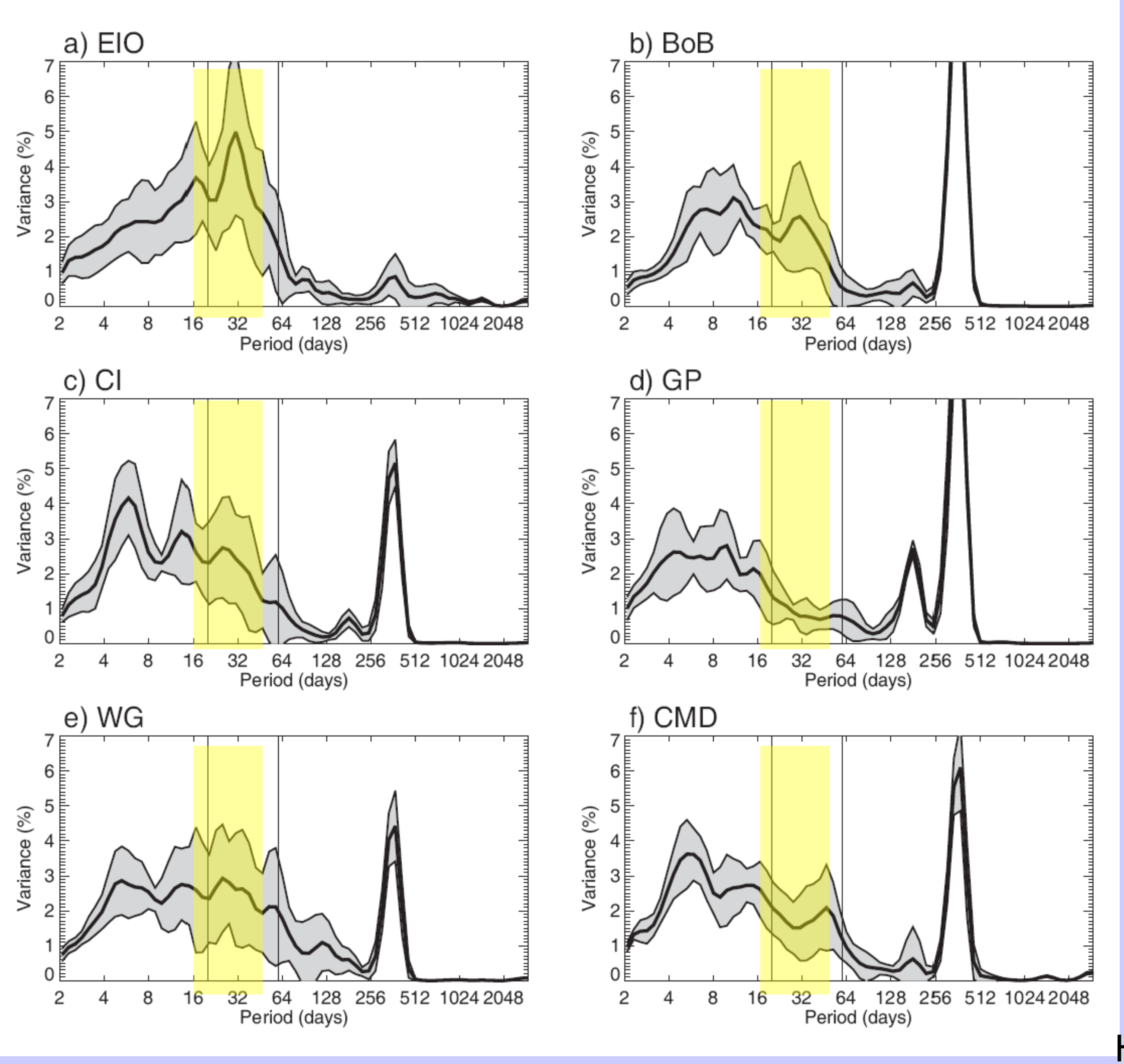


E.g., Bay of Bengal Wavelet Spectrum



Hoyos & Webster (2007)

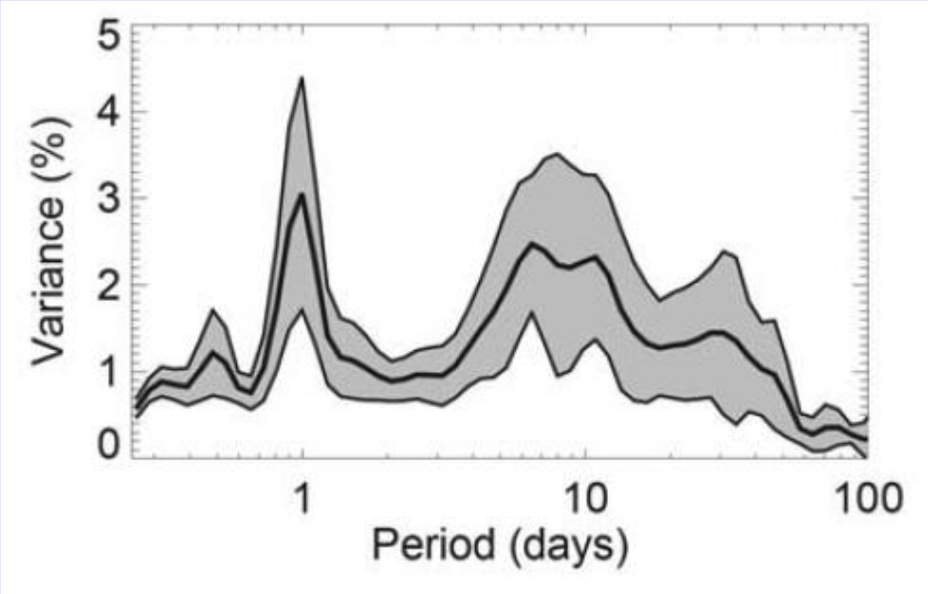
Average Spectra for Summer



What is not obvious from these spectra is that the higher-frequency peaks to the left of the iSO attain maximum intensity during one phase of the iSO!

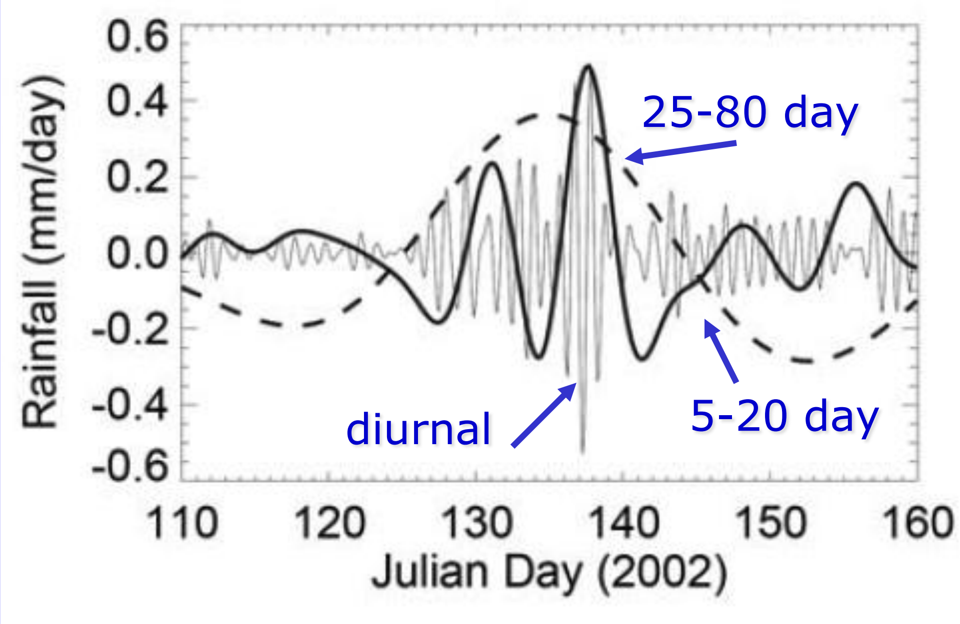
Hoyos & Webster (2007)

Dependence of multi-scale variance on intraseasonal time scale



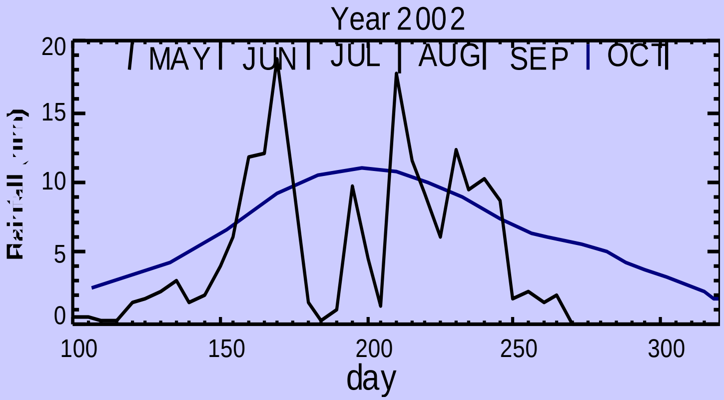
TRMM spectra of 3-hourly rainfall over Bay of Bengal

TRMM data organized into three spectral bands (diurnal, 5-20 days and 25-80 day). Summer 2002

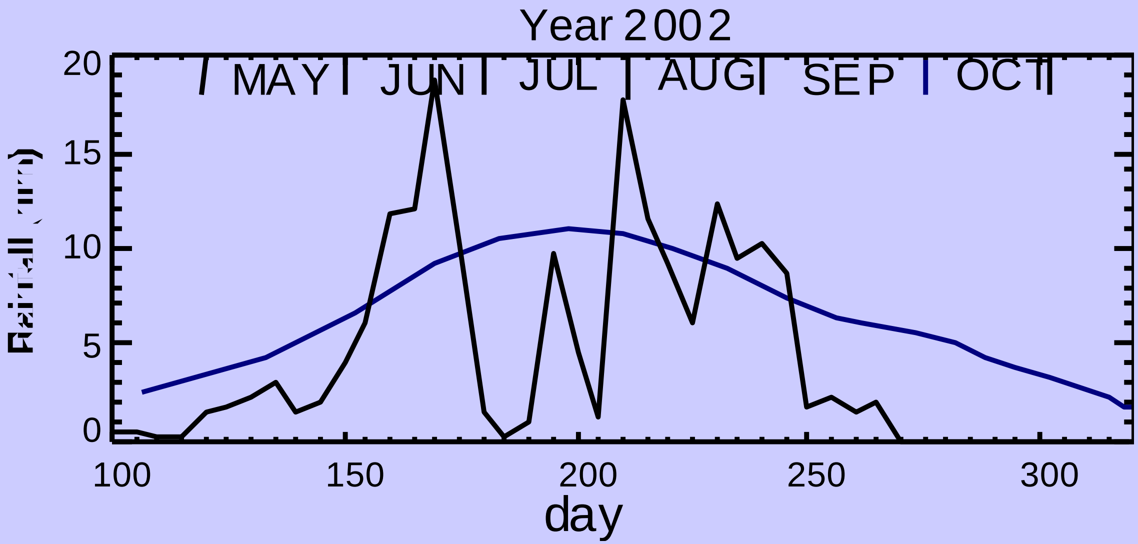


Some practical considerations

- Given the importance of ISO variability, there is an urgency to provide forecasts
- Strategic versus tactical decisions
- <u>Three-tier approach</u>: Forecasting one time scale is not enough:
  - Seasonal (strategic)
  - Intraseasonal (tactical)
  - Weather (tactical)



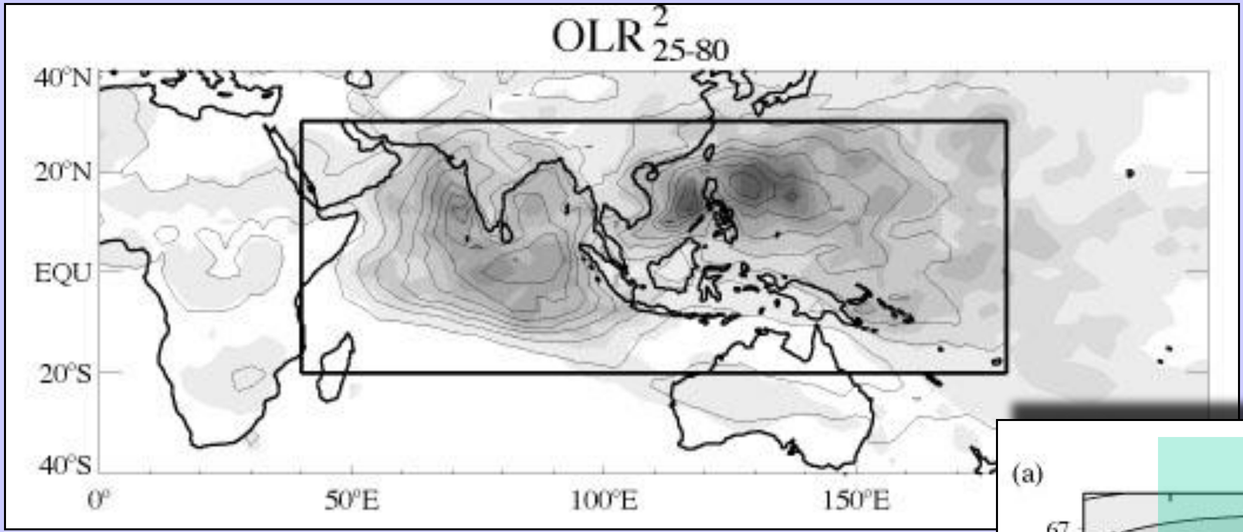
From an applications viewpoint, 20-25 day prediction is most useful:



Discussing the 2002 drought over central India, A. R. Subbiah noted:

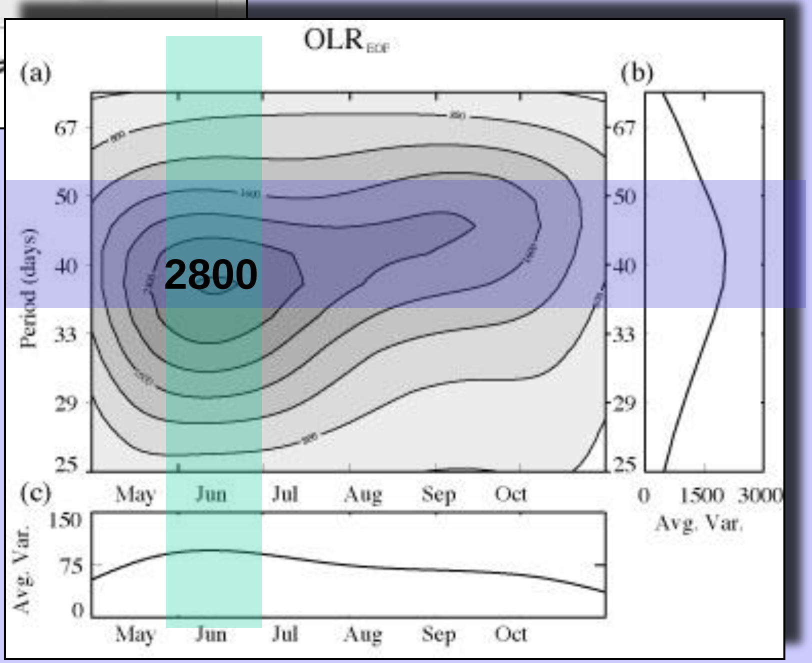
"The minimum length of time of a forecast that will allow a farming community to respond and take meaningful remedial actions … about 10 days although 3 weeks would be optimal… Assuming (such) were available by the third week of June 2002… farmers could have been motivated to postpone agricultural operations saving investments worth billions of dollars… water resource managers could have introduced water budgeting measures…"

External influences on ISO behavior

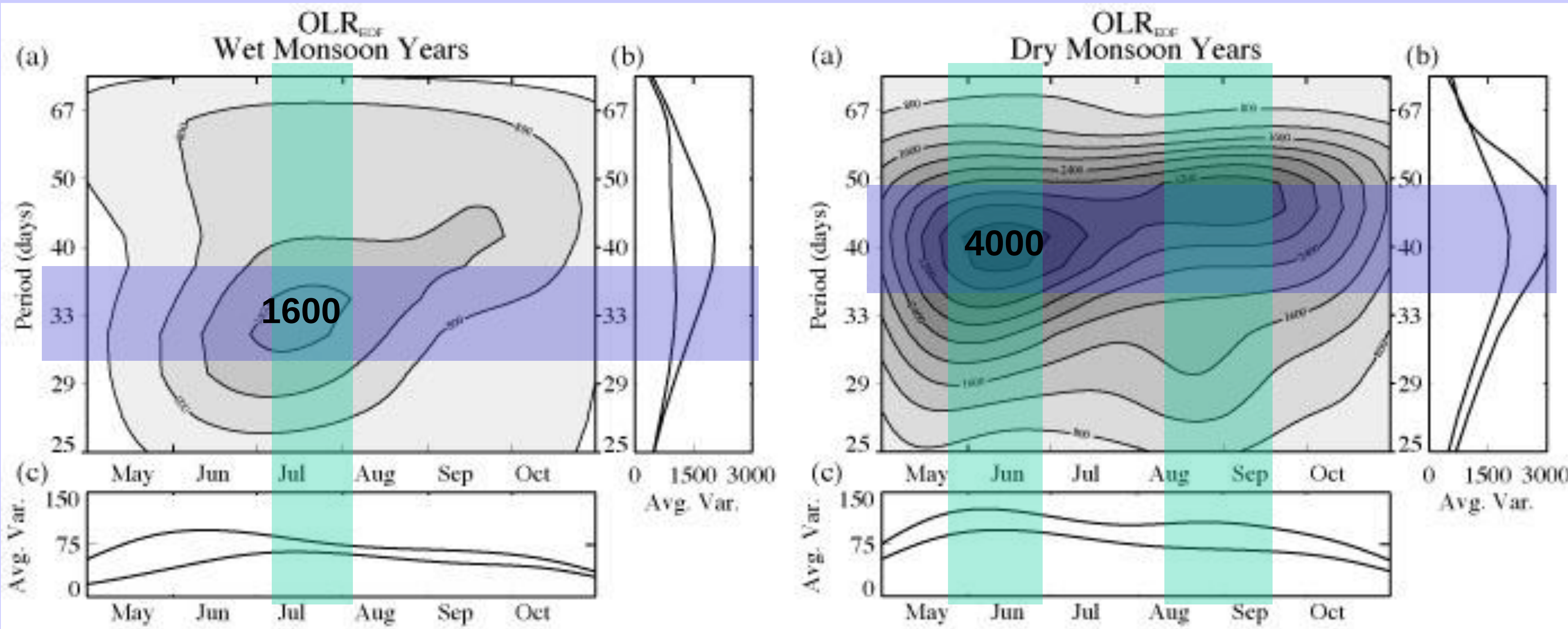


OLR variance in 25-80 day band

- Maximum variability occurs at 40 days and early in season
- If we knew ahead of time what were the characteristics of the coming season could we forecast the character of the ISO?



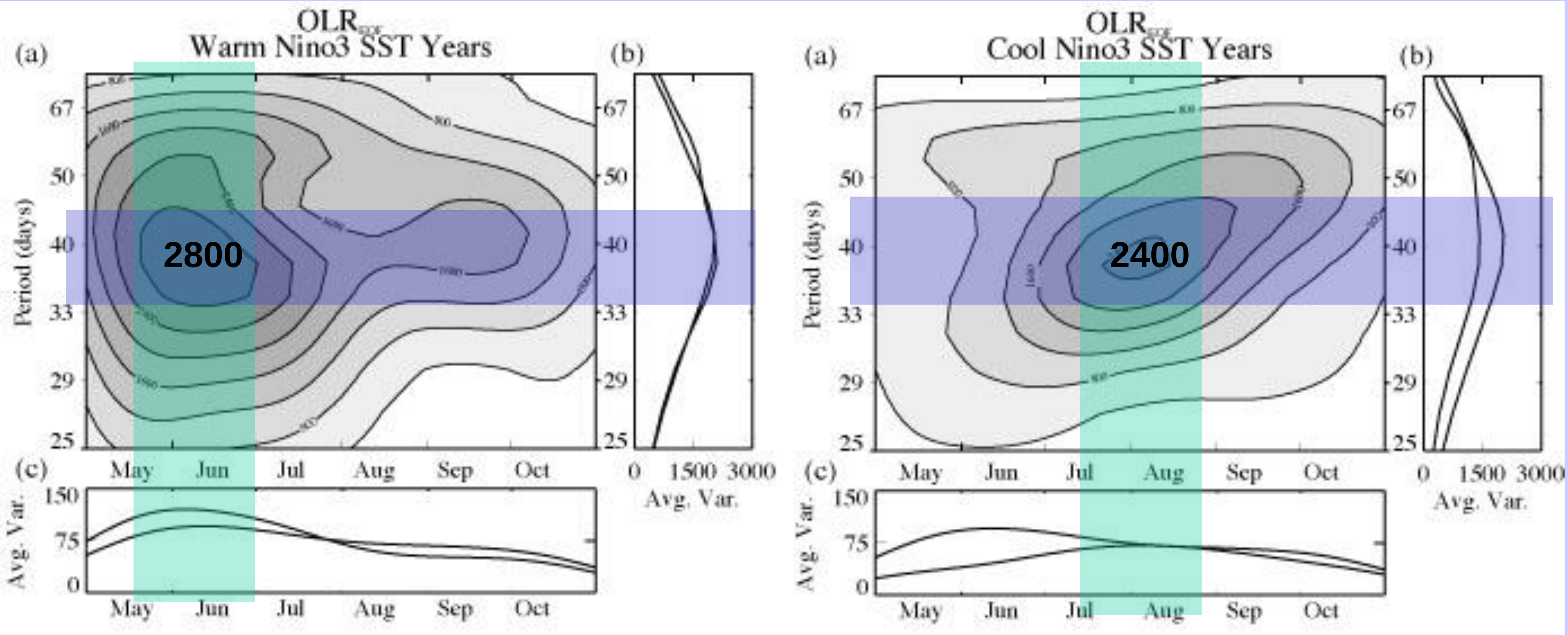
Variability of ISO characteristics as function of monsoon "strength"



Shorter period active/ break sequences occurring later than climatology

More frequent higher amplitude oscillations occurring throughout of summer

ISO variance as function of state of El Nino/La Nina



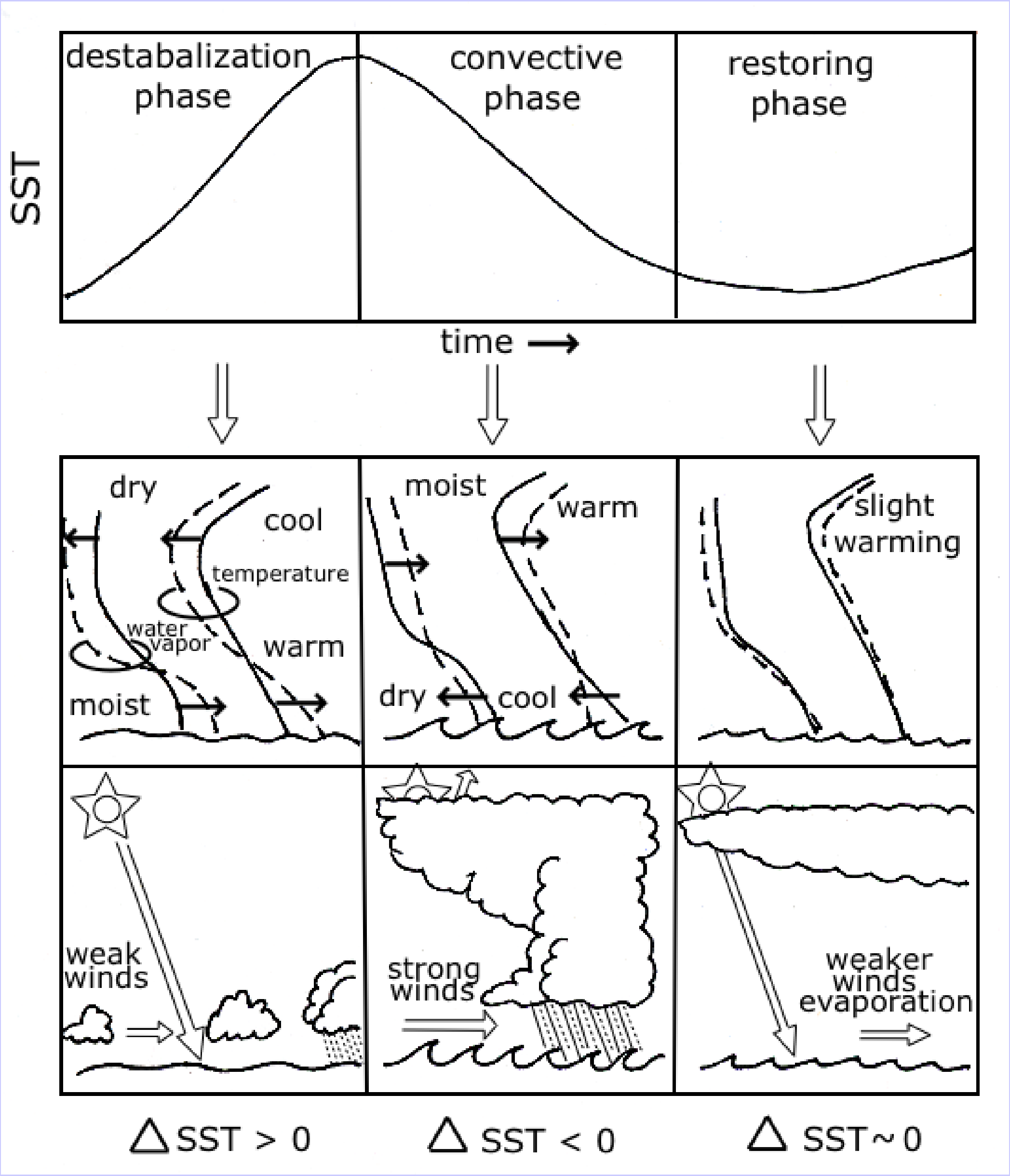
Active/ break sequences occurring earlier than climatology (delayed onset?)

Active/ break sequences occurring later than climatology

Summary:

- Largest difference occurs between strong and weak years but spectra shown was for extreme years and there is little skill in forecasting these events.
- No skill in forecasting within sd range but little difference in in ISO characteristics then anyhow
- Smaller difference between El Nino and La Nina years but lead time of ENSO forecasts short for summer monsoon season.
- This leaves empirical and numerical modeling and prediction of individual ISO events

Simple model of intraseasonal variability



Three phases of ISO:

(1) Destabilization

(2) Convective

(3) Restoring

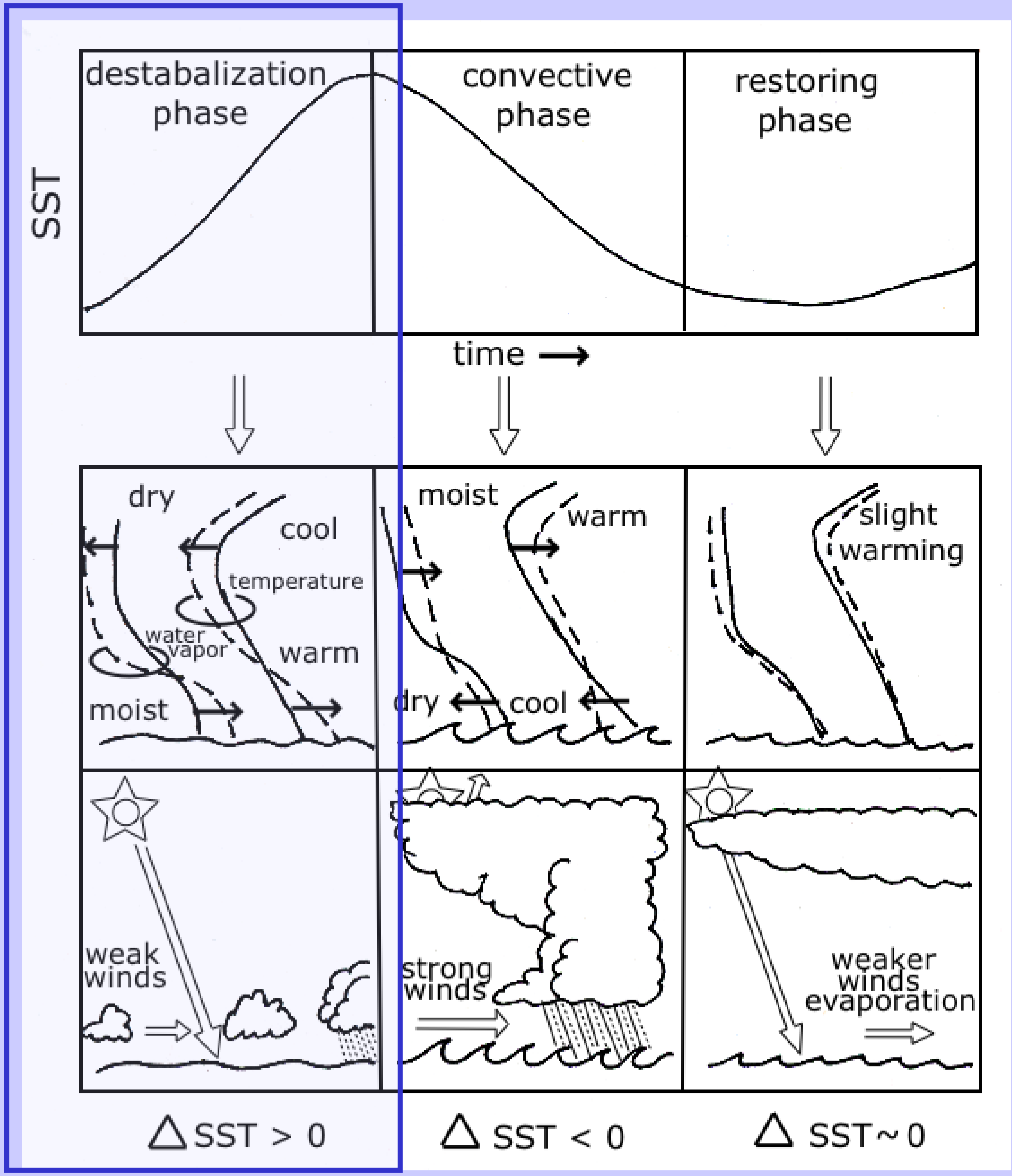
Involve dynamics, thermodynamics, clouds, oceans

Stephens, Webster.. (2004) J.Clim

Wang, Webster, Teng (2005) GRL

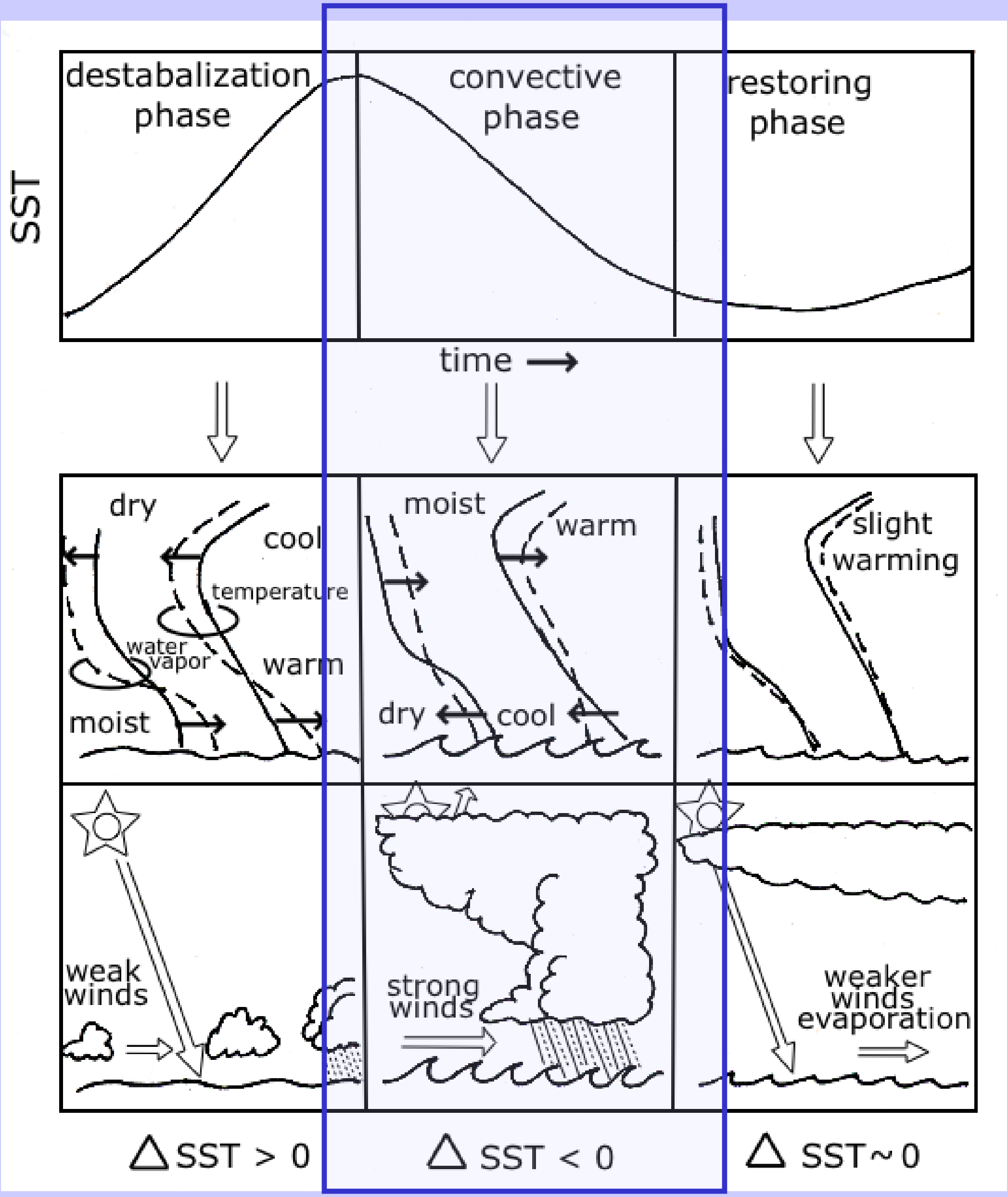
But, does not define genesis region or time scale

Destabilization Phase:



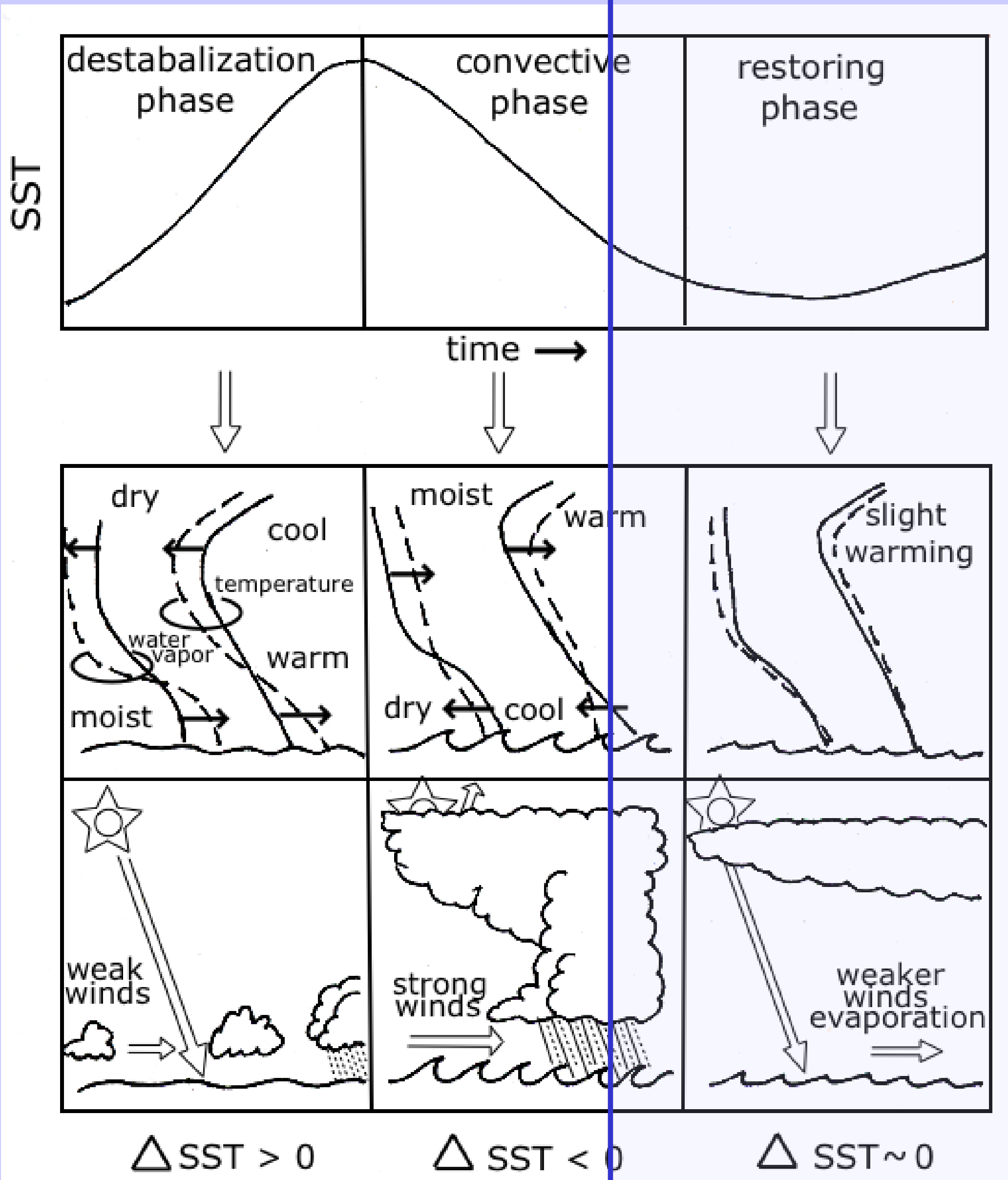
- Strong subsidence
- Strong surface heating SST increasing
- Upper cooling, lower heating
- Trade Cu, Cumulus humulis mixing
- Build up of CAPE

Convective Phase:



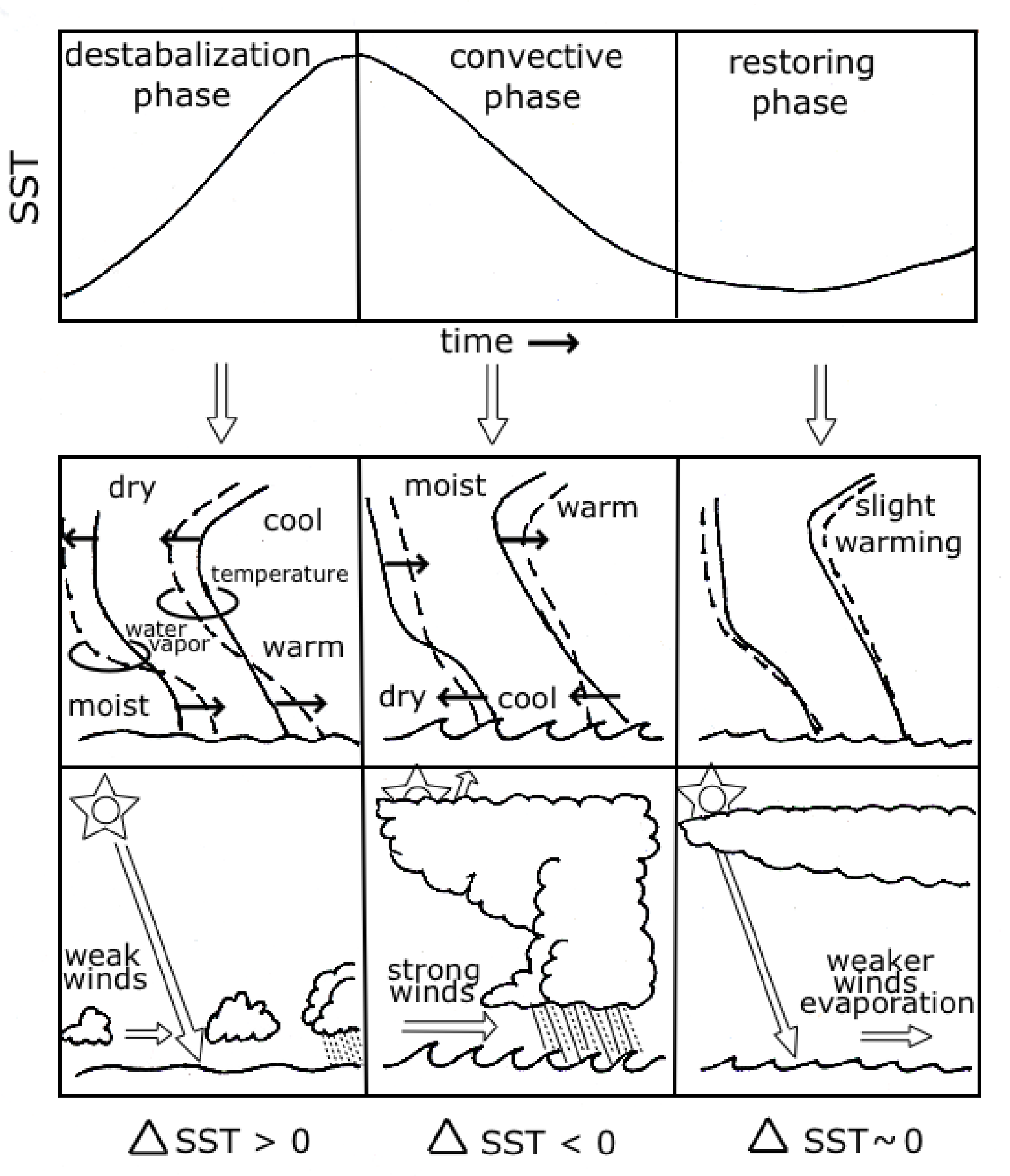
- Release of CAPE with deep convection
- Projection onto equatorial modes (coupled or uncoupled??)
- Stronger winds
- Cooling of ocean

Restoring Phase:



- Mode propagation
- Stratus phase
- Upper level heating
- SST starts to increase

Instability of the coupled system?



Collectively, the three phase system sets the time scale of the ISO

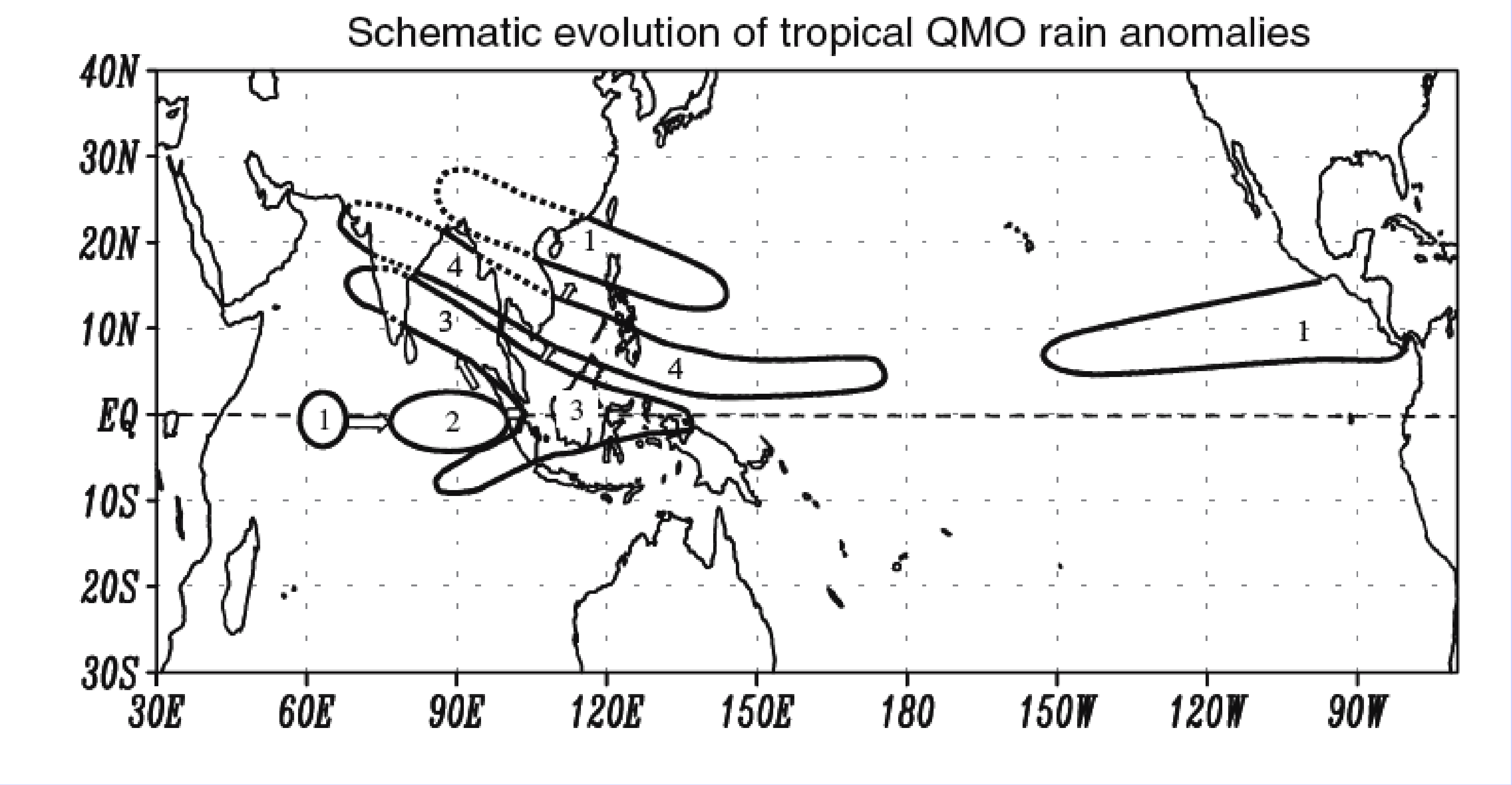
An integral component of each phase of this simple ISO is cloudiness

Interaction of clouds, dynamics & thermodynamics of A/O system determine timescale of system

Errors in cloud parameterizations create error cascade to longer periods

Demands on model are great

Bin’s question: Why does northward propagation take place?

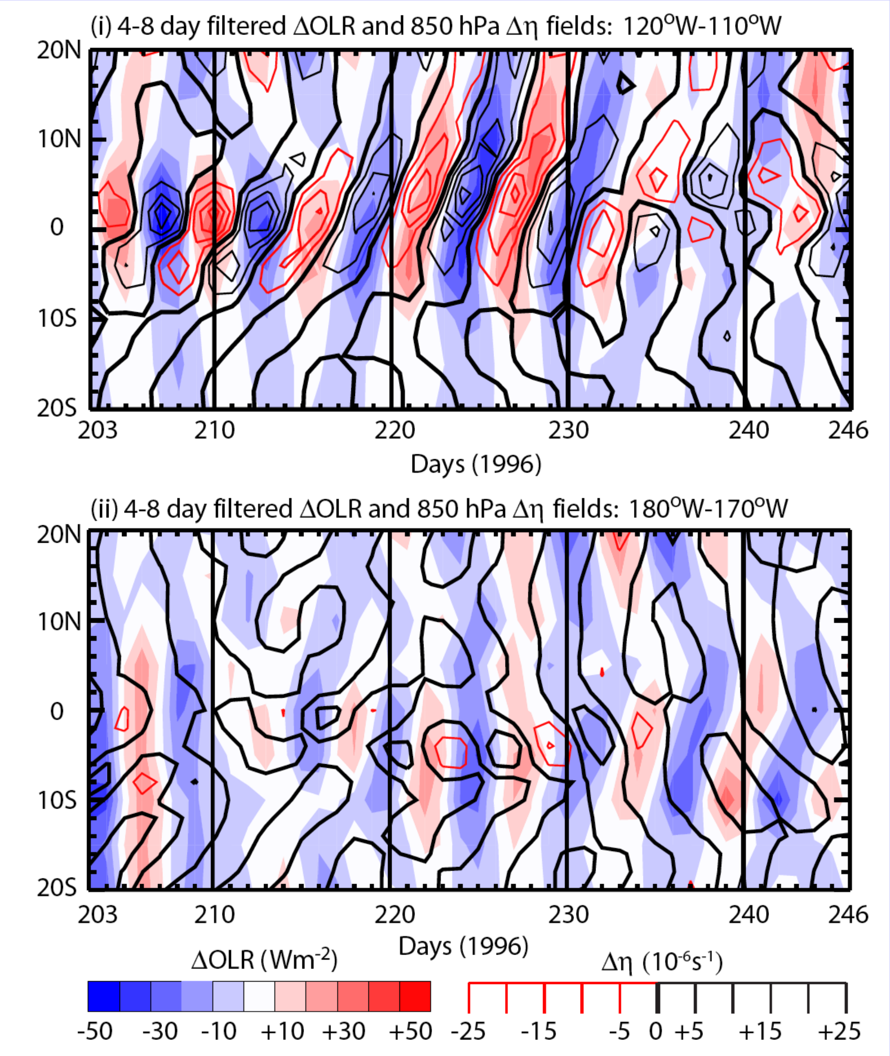


Northward propagations take place in all regions where cross-equatorial pressure gradient is large (tomorrow):

Strong cross-equatorial pressure gradients in (1) as well as in Indian Ocean where gradient is factor of 2 larger than 1.

High-frequency propagations in moderate and weak CEPGs

OLR and absolute vorticity anomalies



East Pacific (moderate CEPG)

Central Pacific (zero CEPG)

Toma & Webster (2007)

Tomas et al. (2000) show that in strong CEPG (e.g., NIO) that nonlinearity and time scale propagation change. Lots of very basic dynamics still have to be understood………

So, what can we do? Options:

- Improve parameterizations, coupling boundary layer processes and radiative fluxes: Long term (remember Charney)
- Go to cloud resolving models, super-param and etc…. Long term for operational use (computer).
- Use multi-ensemble model approach: Krish super-ensemble approach: (is this restricted by param problems, too?)
- Note that empirical relationships show considerable predictability:
    - Just use empirical methods for prediction
    - Modify couple O/A model using knowledge gained from empirical methodology

Forecasting of Intraseasonal variability

Coupled Ocean-Atmosphere modeling:
Traditional approach. Series of experiments will show that errors grow rapidly and predictability is rapidly eroded by error growth (convection?)

Bayesian Empirical Prediction:
Conditional probability scheme provides 20-day forecasts using a
Banded wavelet technique. Banding "protects" longer term variability
In time series from high frequency noise

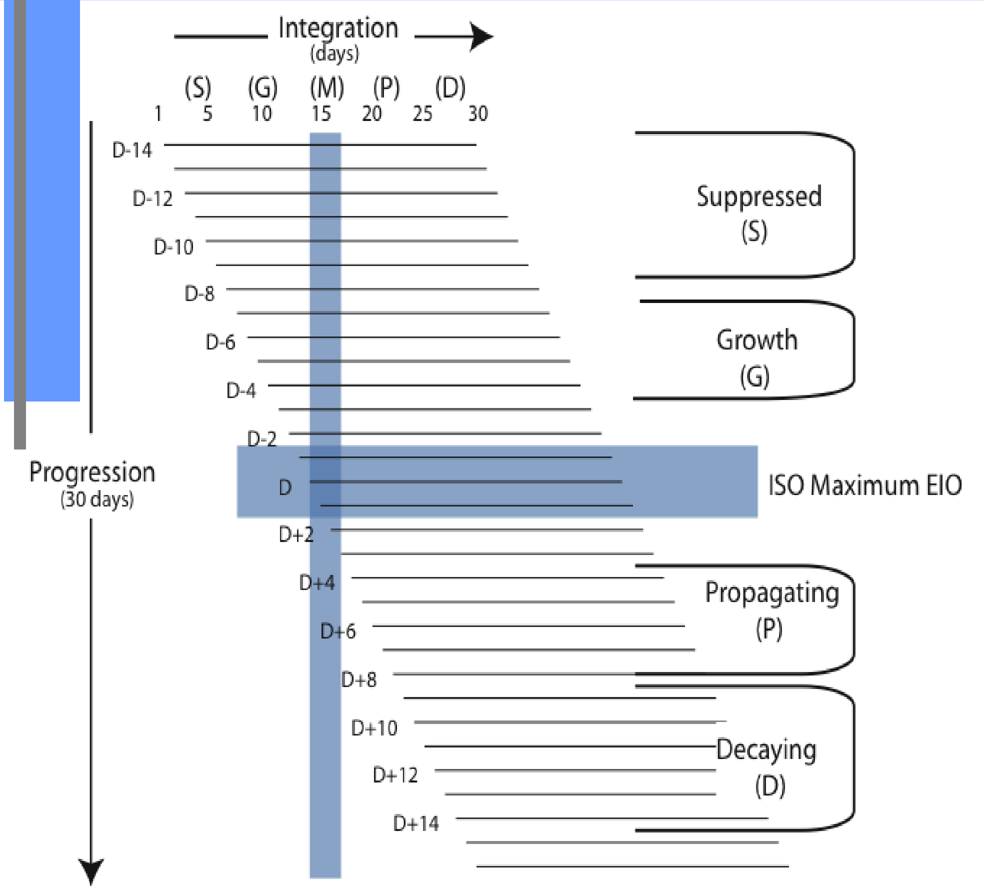
Slow manifold Modeling:
Takes coupled ocean-atmosphere model and applies "banding" technique
Allowing operational (real-time) 30-day forecasts. Early results suggest
Considerable skill using this method.

SERIAL MODELING:ECMWF COUPLED MODEL

- Series of experiments runs using the ECMWF and Korean climate model (Kim and Kang) coupled operational climate models
- Summer and winter cases
- 30 days of integration initialized each successive day
- 5 ensemble members
- Events chosen so that model initialized before, during and after ISO event to identify when error growth occurs

Experiment sets using coupled Ocean-atmosphere models

Successive daily integration through all phases of ISO life cycle

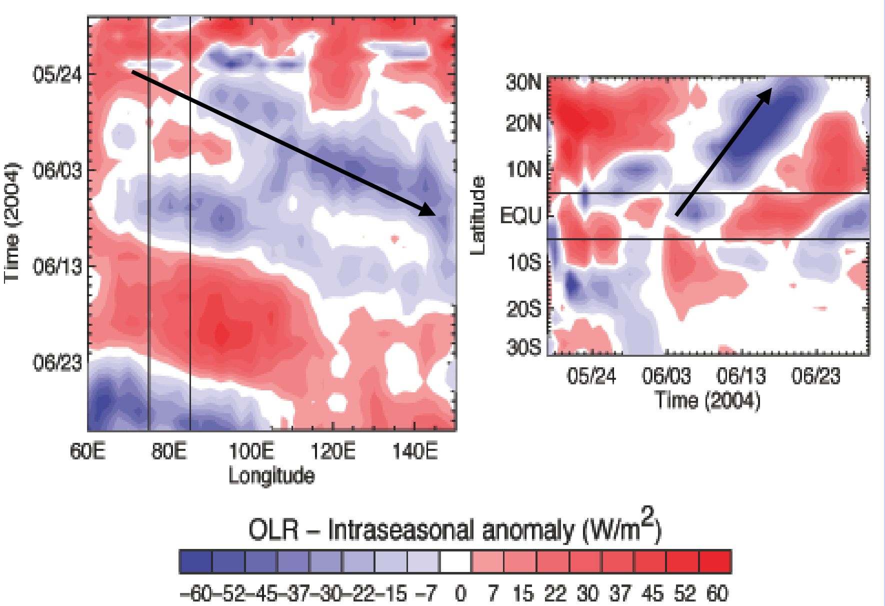


Use ECMWF climate model run for 30 day forecasts on 45 successive days in ensemble mode (5/day)

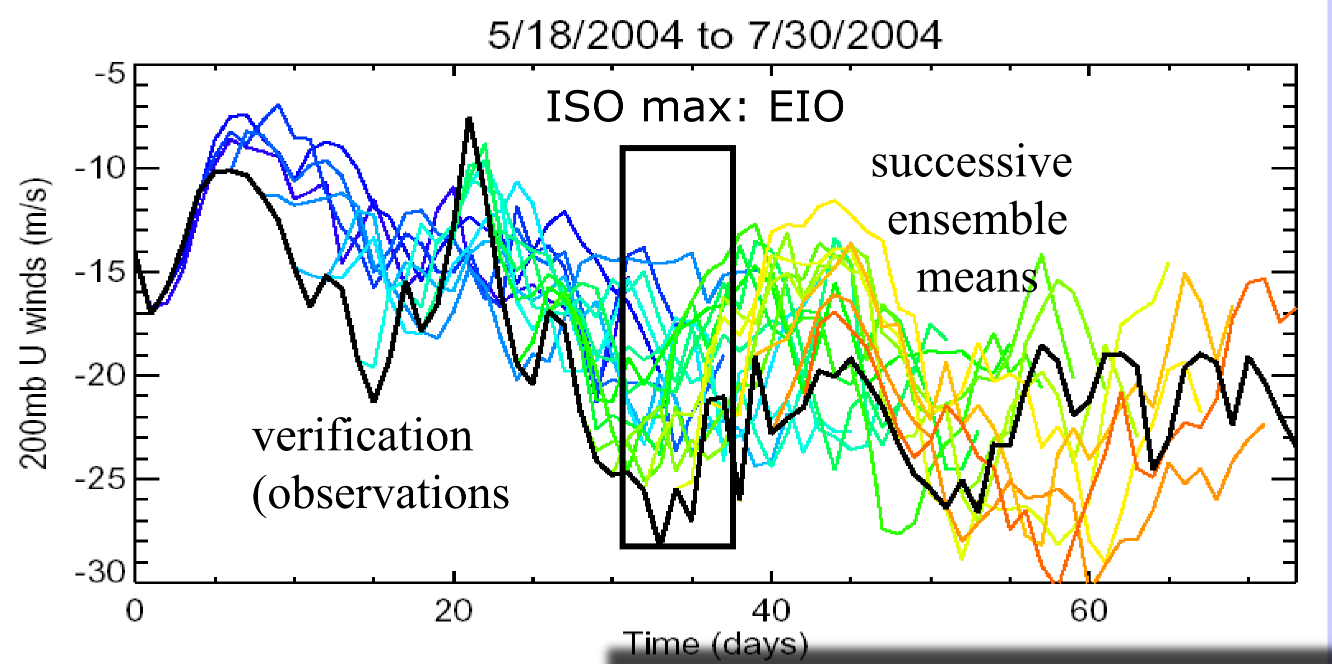
Three cases:

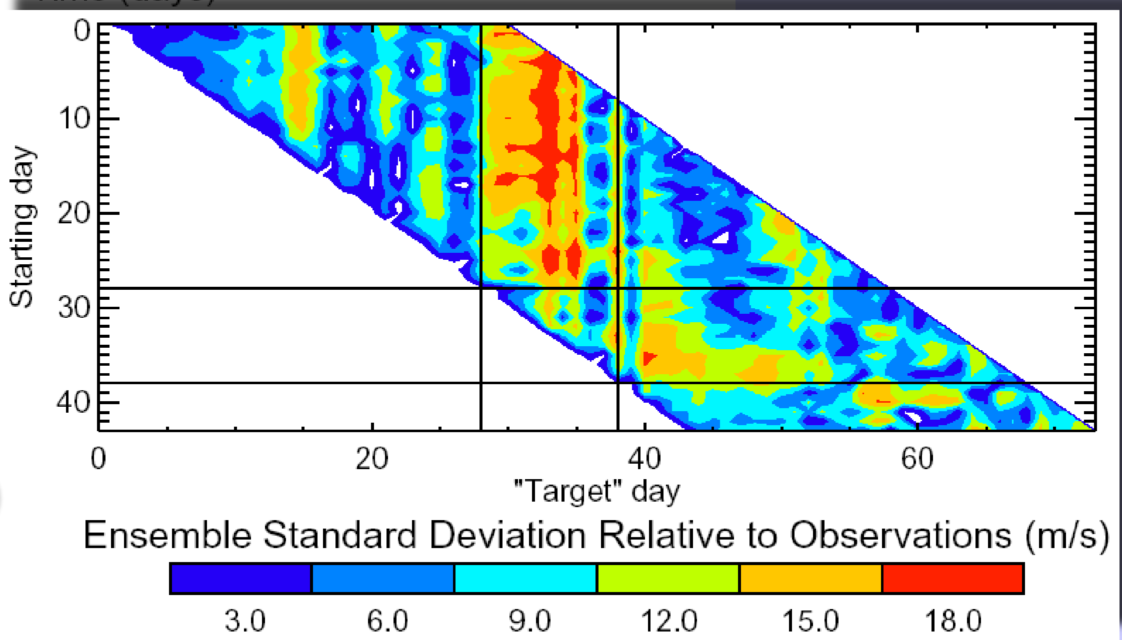
- Winter: TOGA COARE, 1992/93
- Summer: May/June 2004
- Summer 2002

OLR variability through summer case



Results of the Coupled Ocean-Atmosphere Simulations



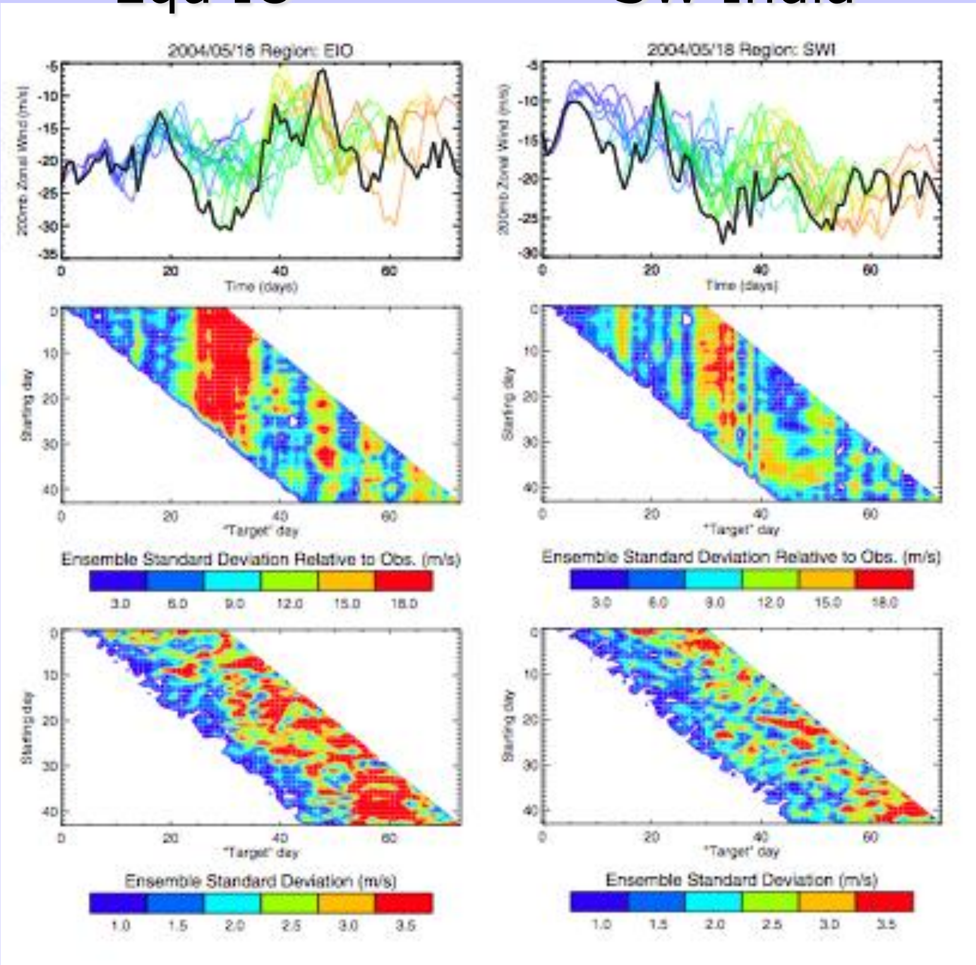


Where do the errors come from that destroy the strong intraseasonal signal?

Hoyos and Webster (2007)
Kim et al. (2007)

Regional errors growth (200 mb wind field) Summer 2004

Equ IO SW India



Errors grow with time and at times of intense convection

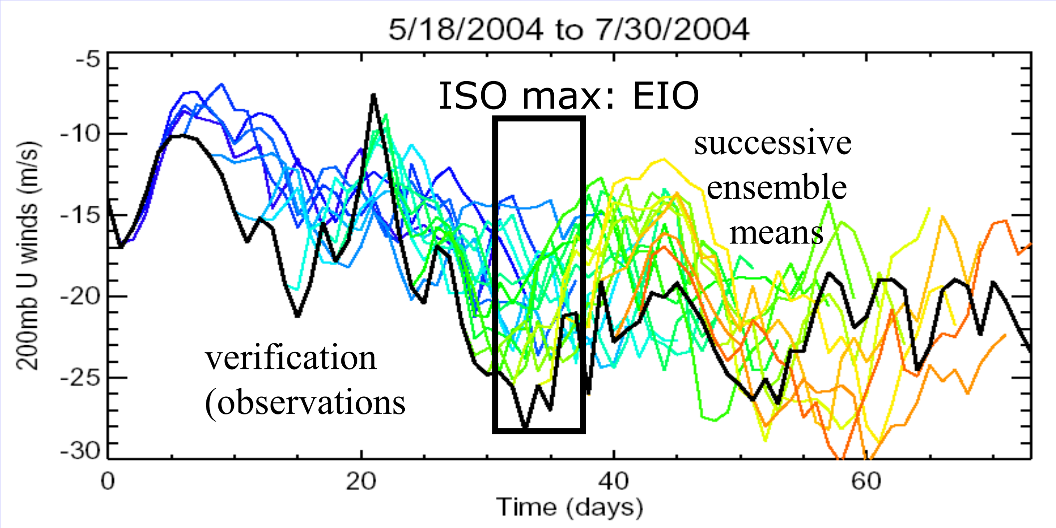
Ensemble mean evolution

Error growth relative to Observations

Error growth in ensemble spread

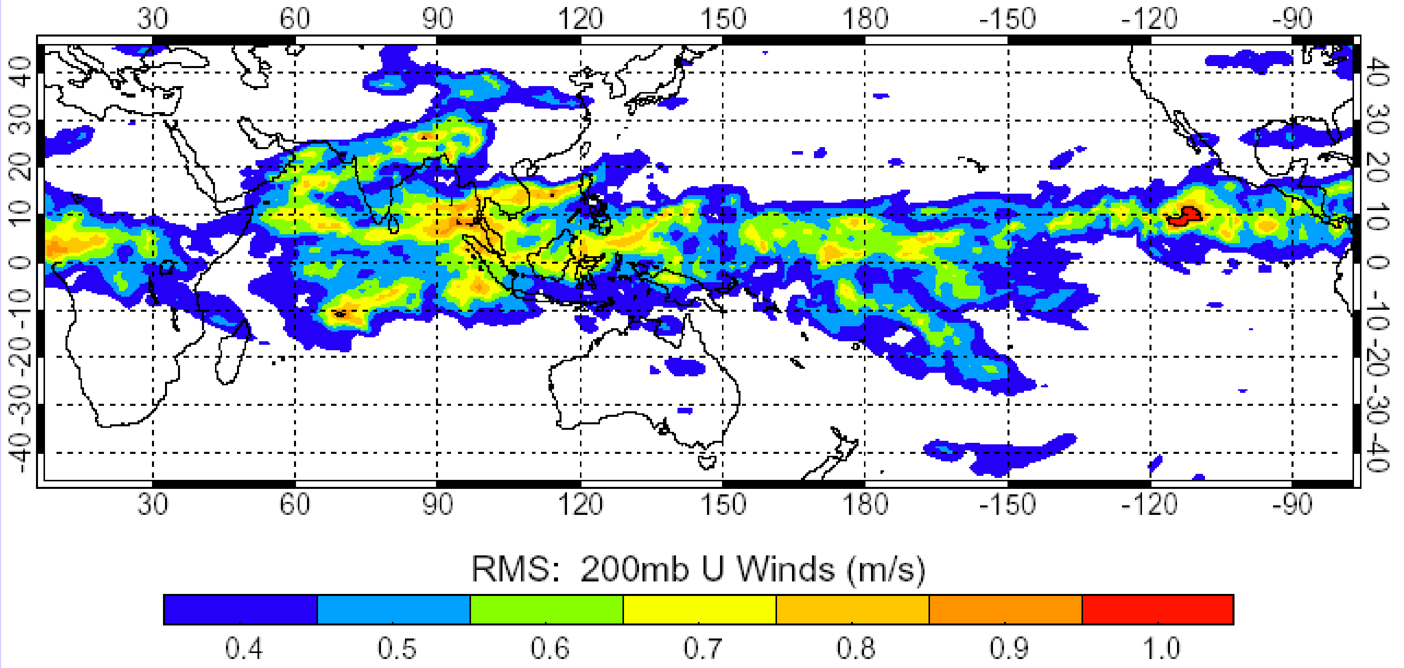
Hoyos and Webster (2007)
Kim et al. (2007)

Where do the errors come from?



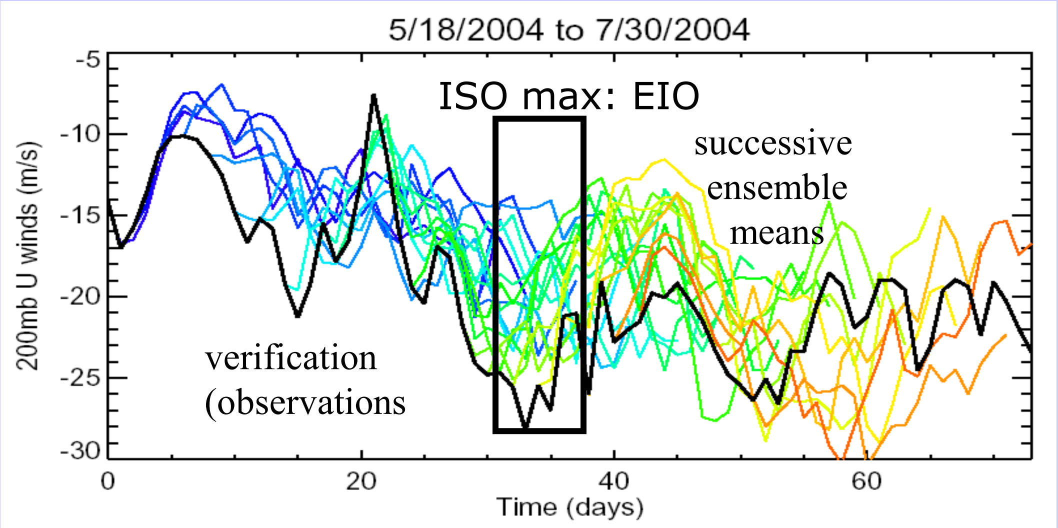
30-day integrations:

Show relatively good predictability out to 10-days except in regions of, or at times of high convective activity of the ISO



Day 1 Errors

Where do the errors come from?



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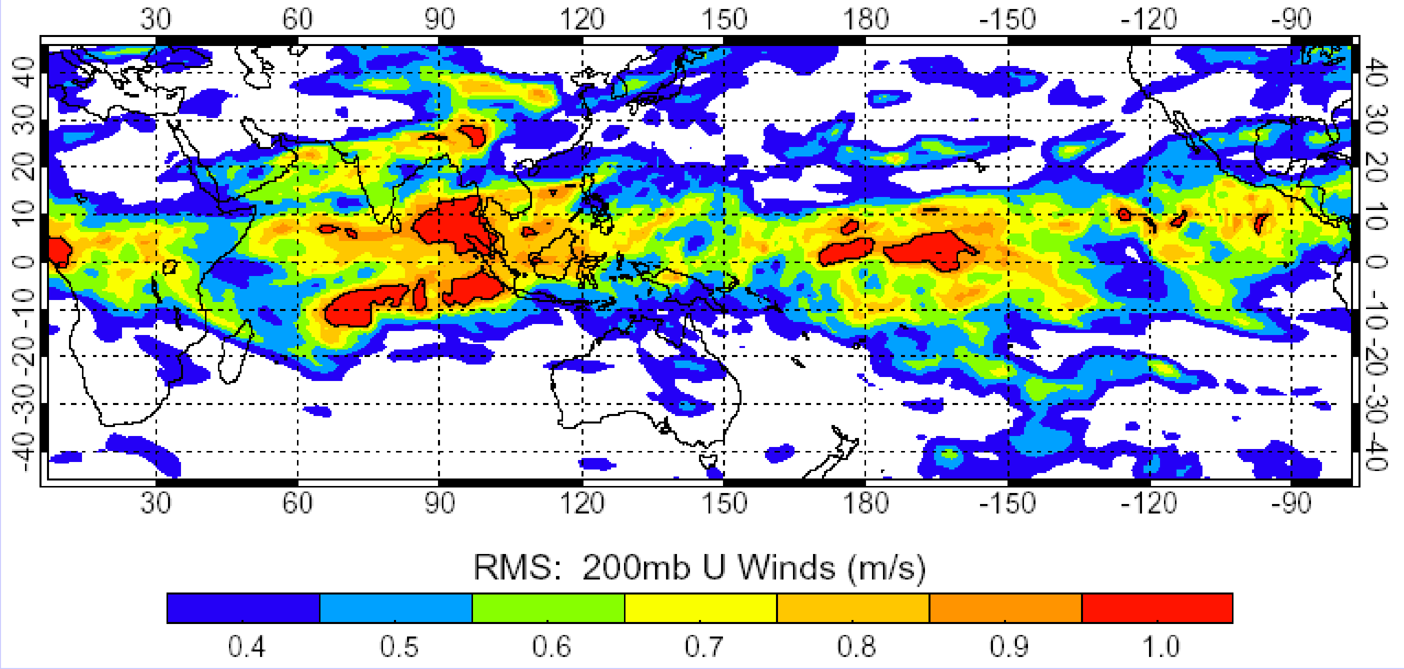
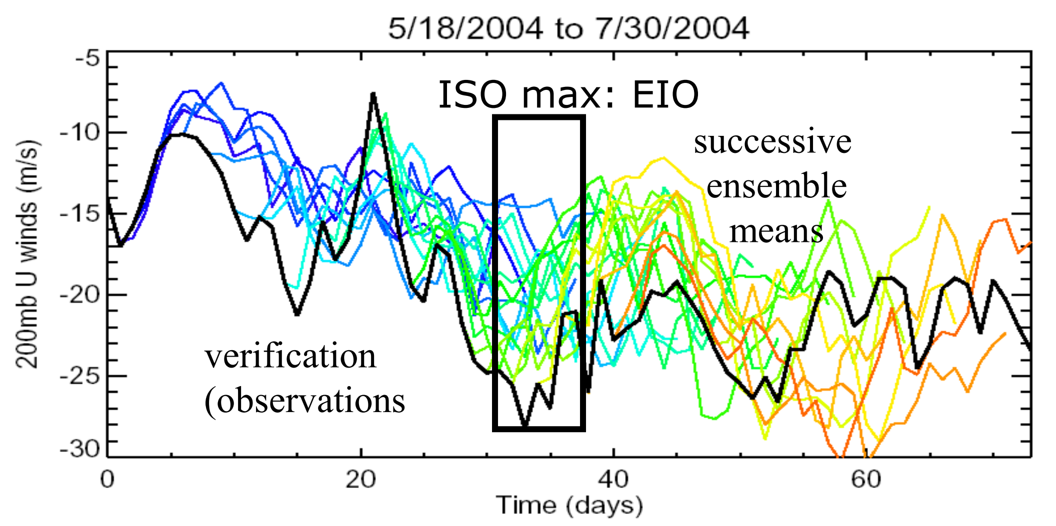


Day 2 Errors

Where do the errors come from?



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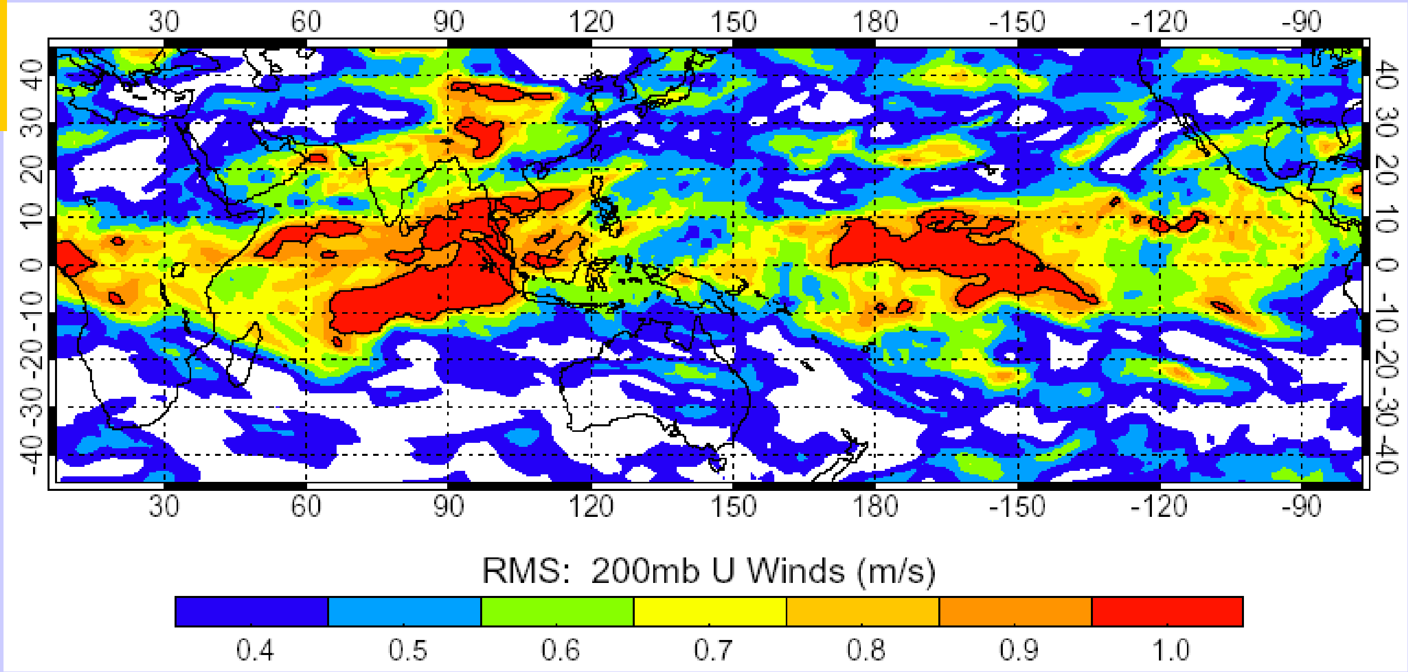
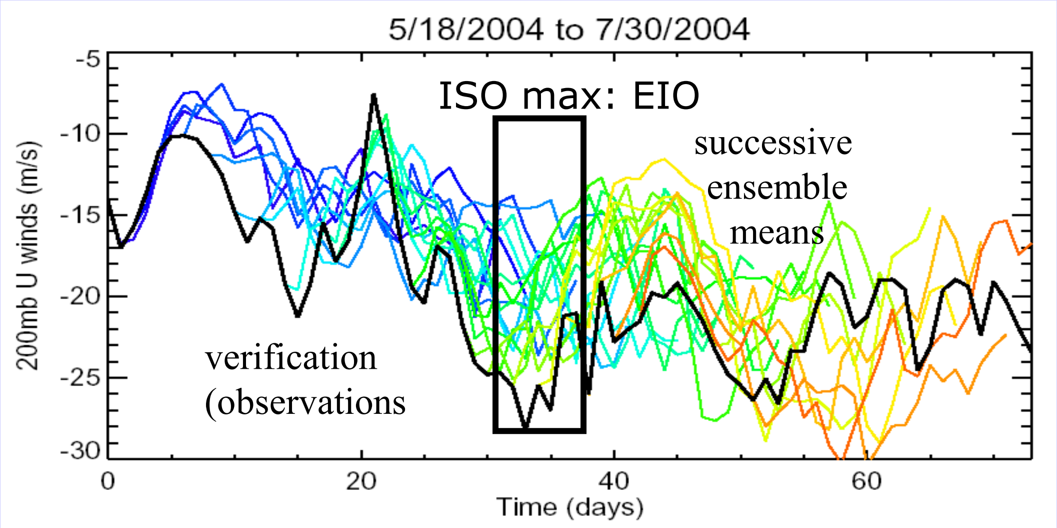


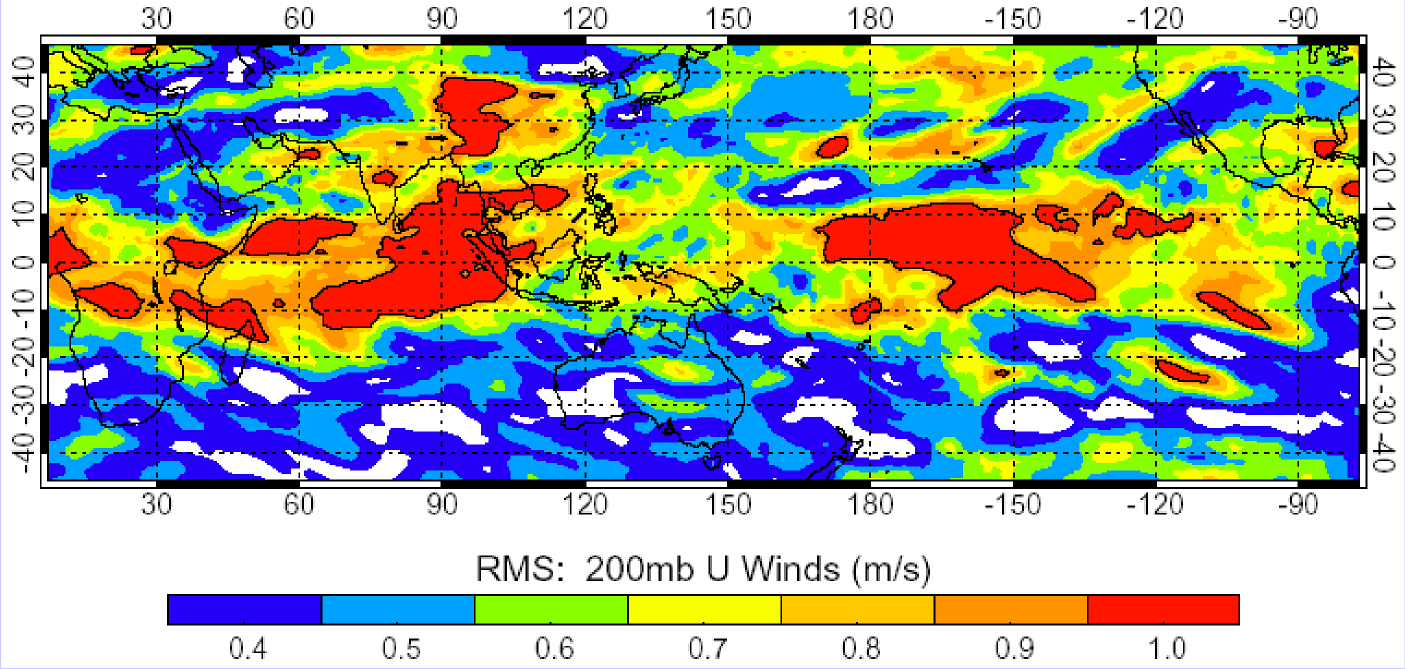
Day 3 Errors

Where do the errors come from?



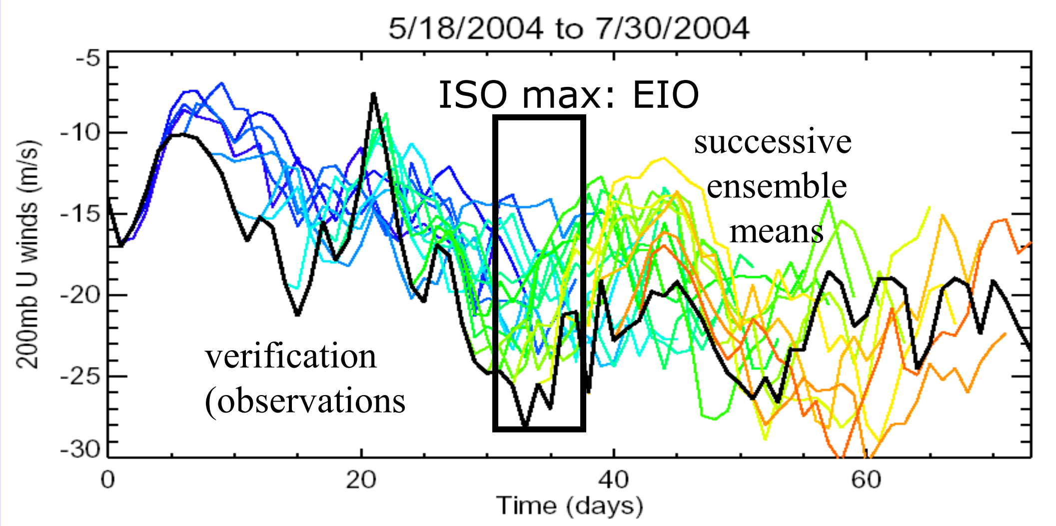
30-day integrations:

Show relatively good predictability out to 10-days except in regions of, or at times of high convective activity of the ISO



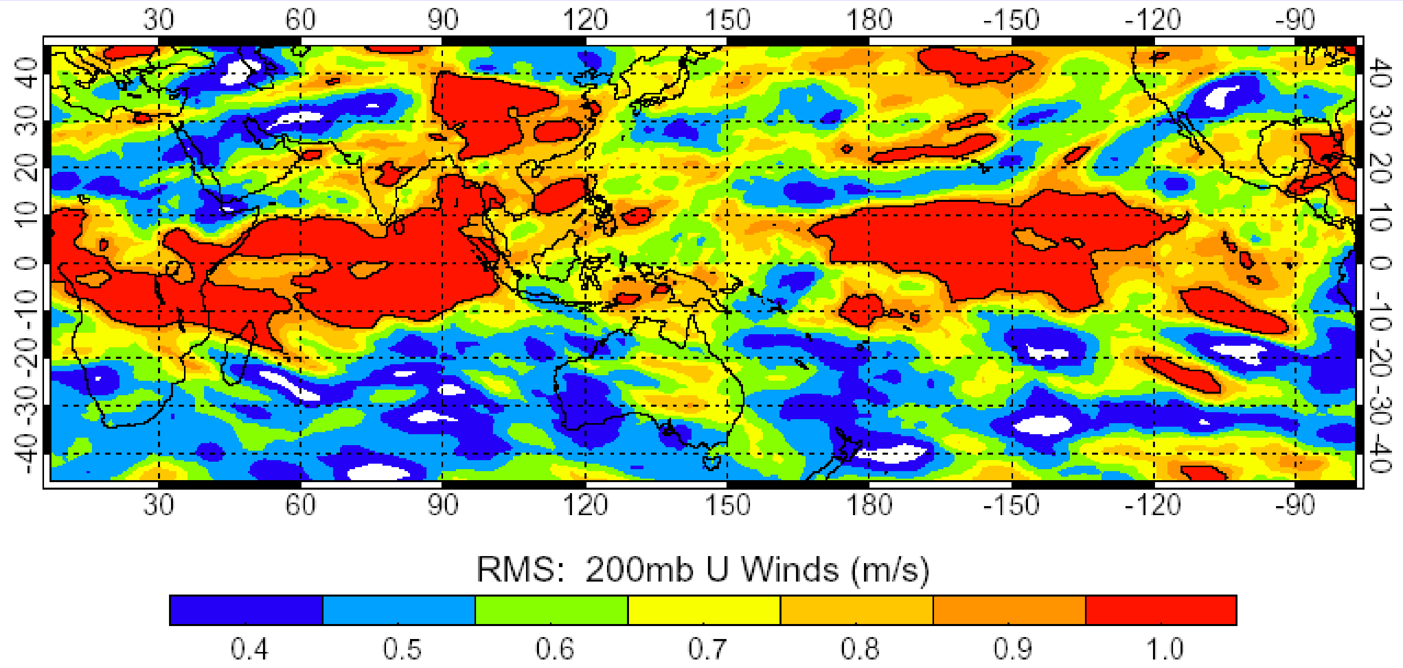
Day 4 Errors

Where do the errors come from?



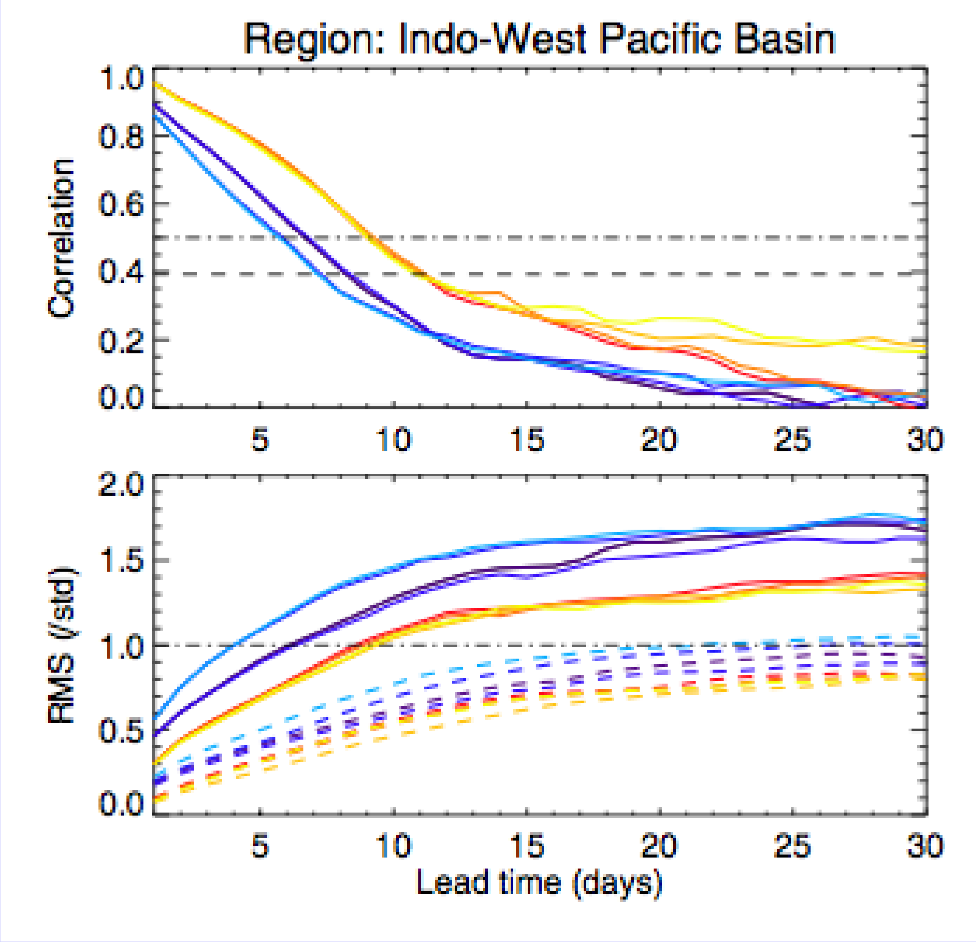
30-day integrations:

Show relatively good predictability out to 10-days except in regions of, or at times of high convective activity of the ISO



Day 5 Errors

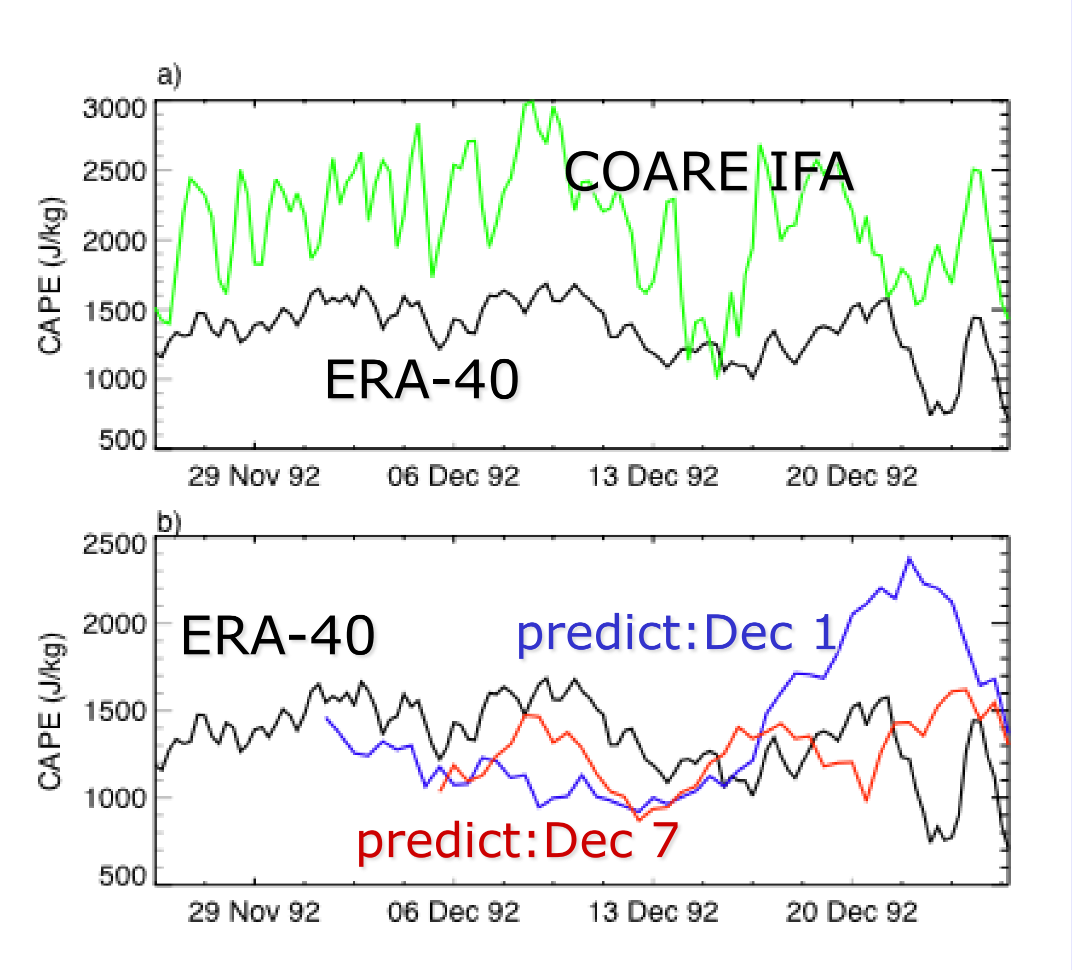
Indian/West Pacific average correlation and RMS error evolution for OLR ( ) and 200 mb winds ( )



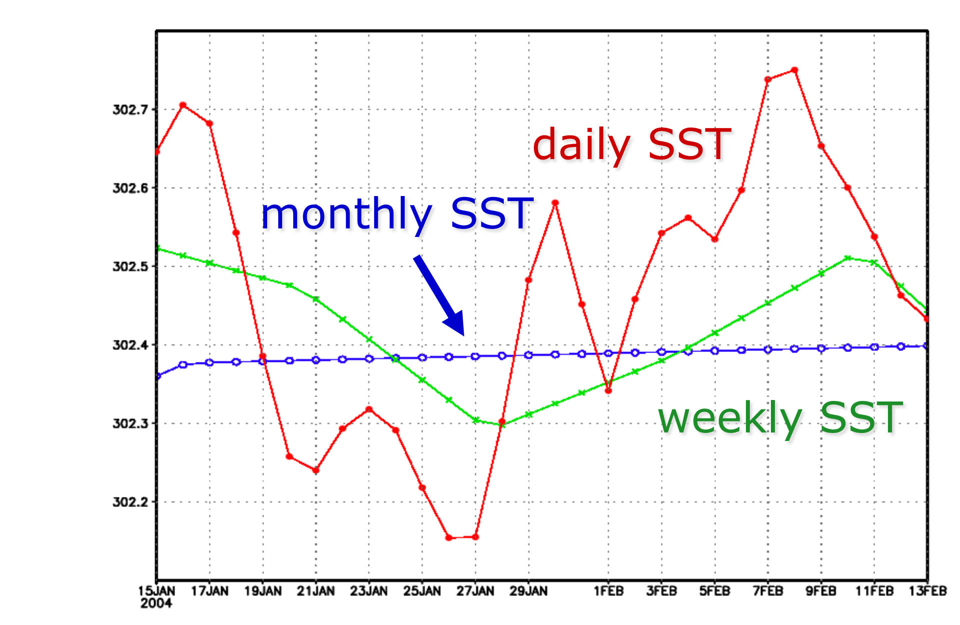
OLR tends to degrade more quickly than dynamic fields

(Hoyos and Webster 2007)

CAPE Comparisons and moisture sensitivity: Winter case: Agudelo et al. (2006)



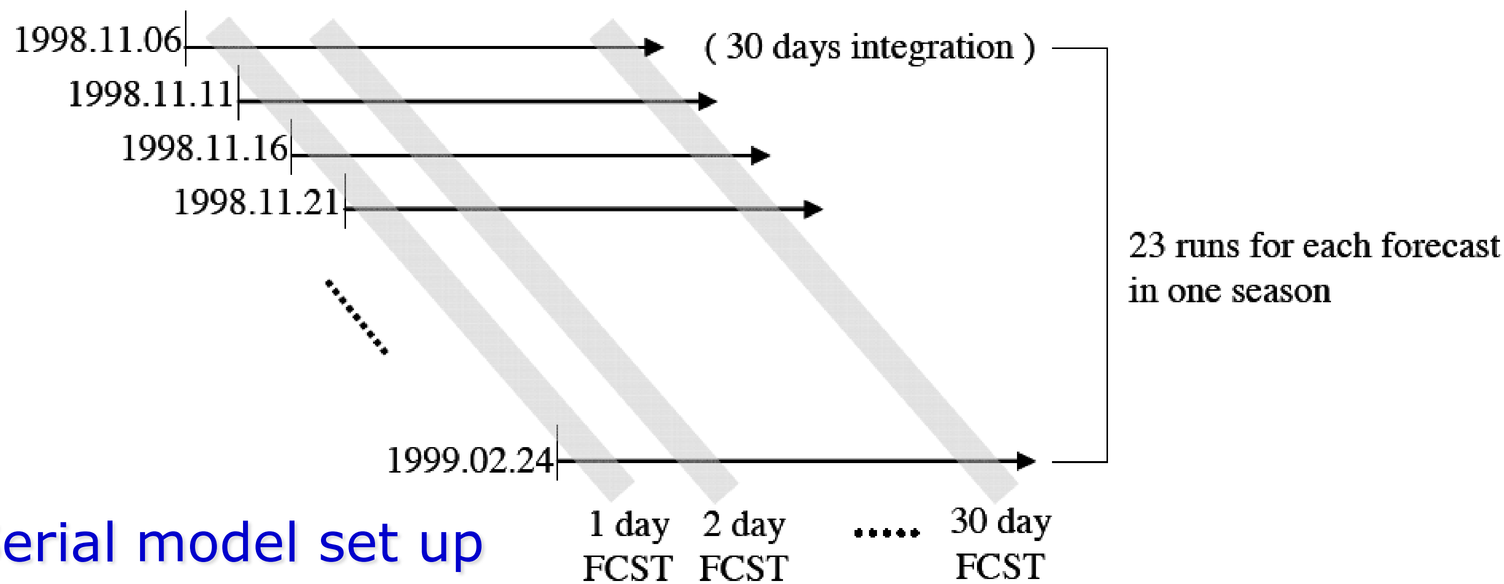
- Model does not simulate well the evolution of CAPE
- Great sensitivity to initial conditions
- Need for model to simulate properly the suppressed and transitional phases of the ISO



Sensitivity of modeled ISO relative to temporal resolution of SST

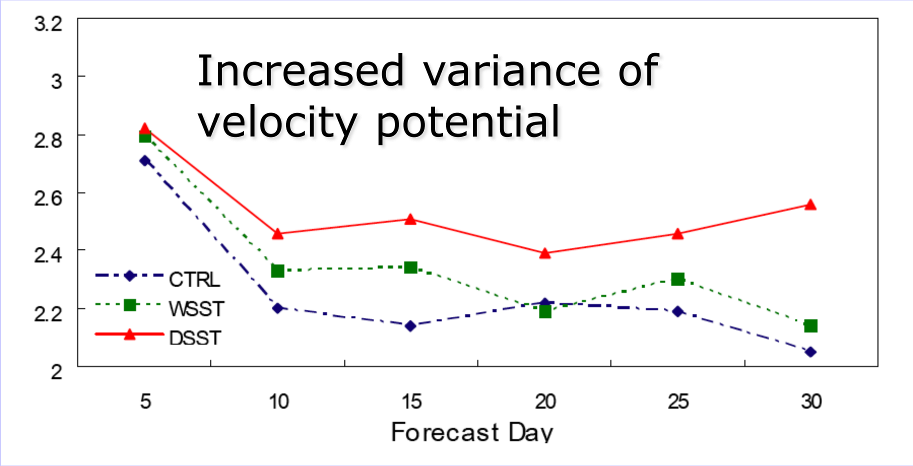
- Serial runs
- Ensemble

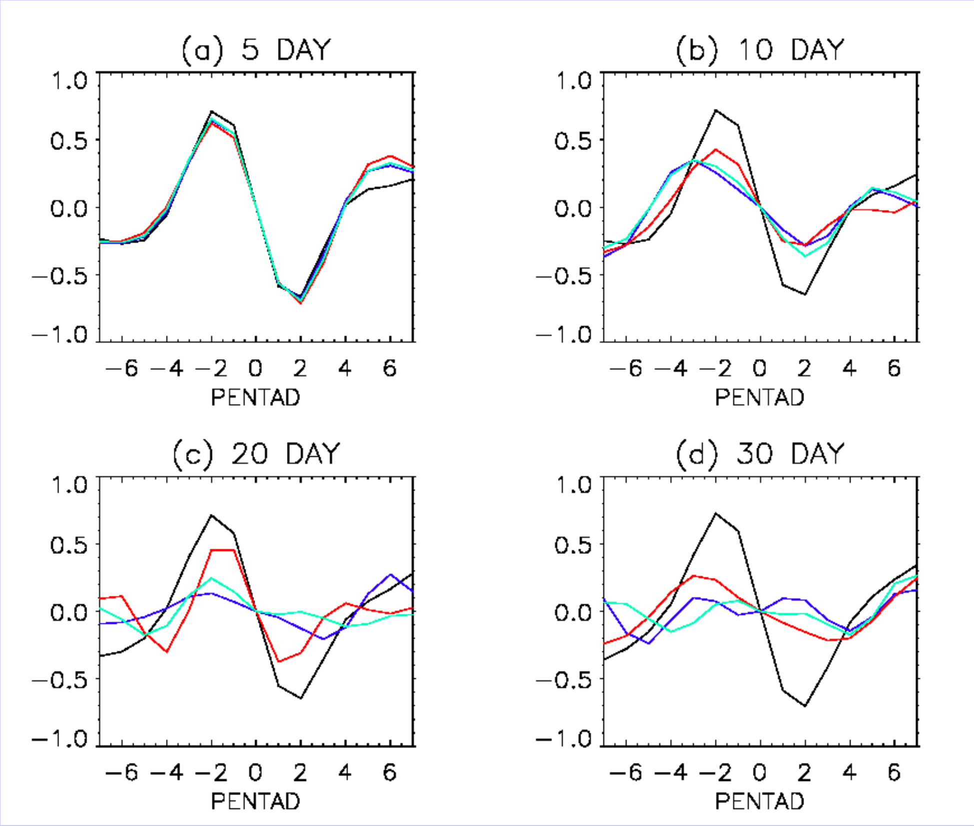
Kim, Hoyos et al. (2008)



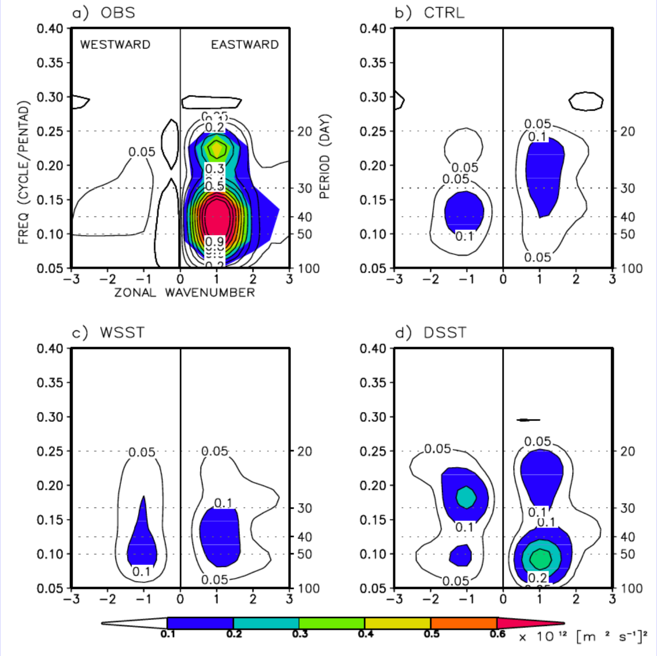
Serial model set up

ISO simulation improved by increasing temporal resolution of SST



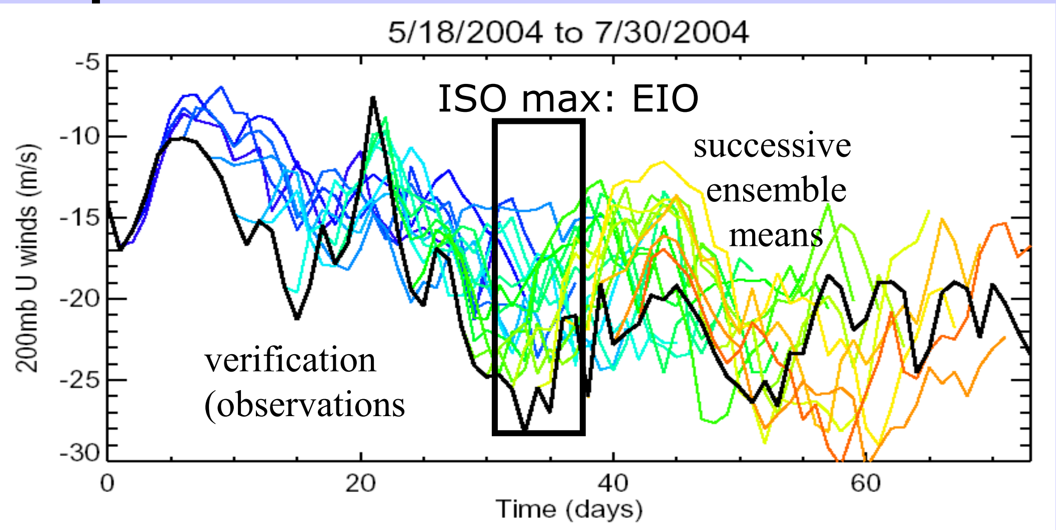


Improved spectral power in MJO band



Improved lag correlation of first two EOFs

SUMMARY of SERIAL INTEGRATIONS



30-day integrations:

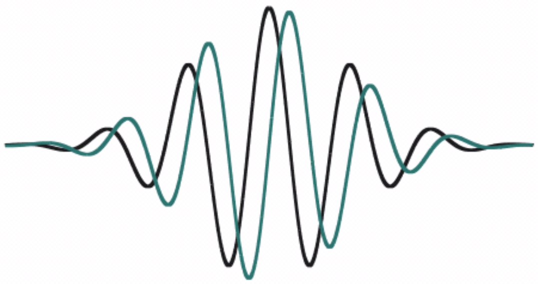
Moderate predictability out to 10 days except in regions and times of deep convection

- Errors rapidly grow in the regions of maximum convection
- Error growth so rapid from small scale convection that variability at longer scales is eroded and loses identity
- As intraseasonal prediction is important and the need is immediate we have to face reality and develop a new modeling paradigm:

Empirical prediction of Monsoon ISO

- Requirements in building an empirical scheme
- The quasi-Bayesian scheme (Webster & Hoyos 2004)
  - physically based (choice of predictors)
  - reduction of error cascade (wavelet banding)
- Rendering the scheme probabilistic and adjusting the Bayesian priors (new work: great promise!)
- Can we learn something from the success in regional empirical prediction

Prediction of Intraseasonal Variability using Bayesian Statistical Schemes



- If the intraseasonal variability (the “slow manifold”) is destroyed by the rapid growth of errors from convection parameterization errors, is it possible to protect the slow manifold using statistical techniques?

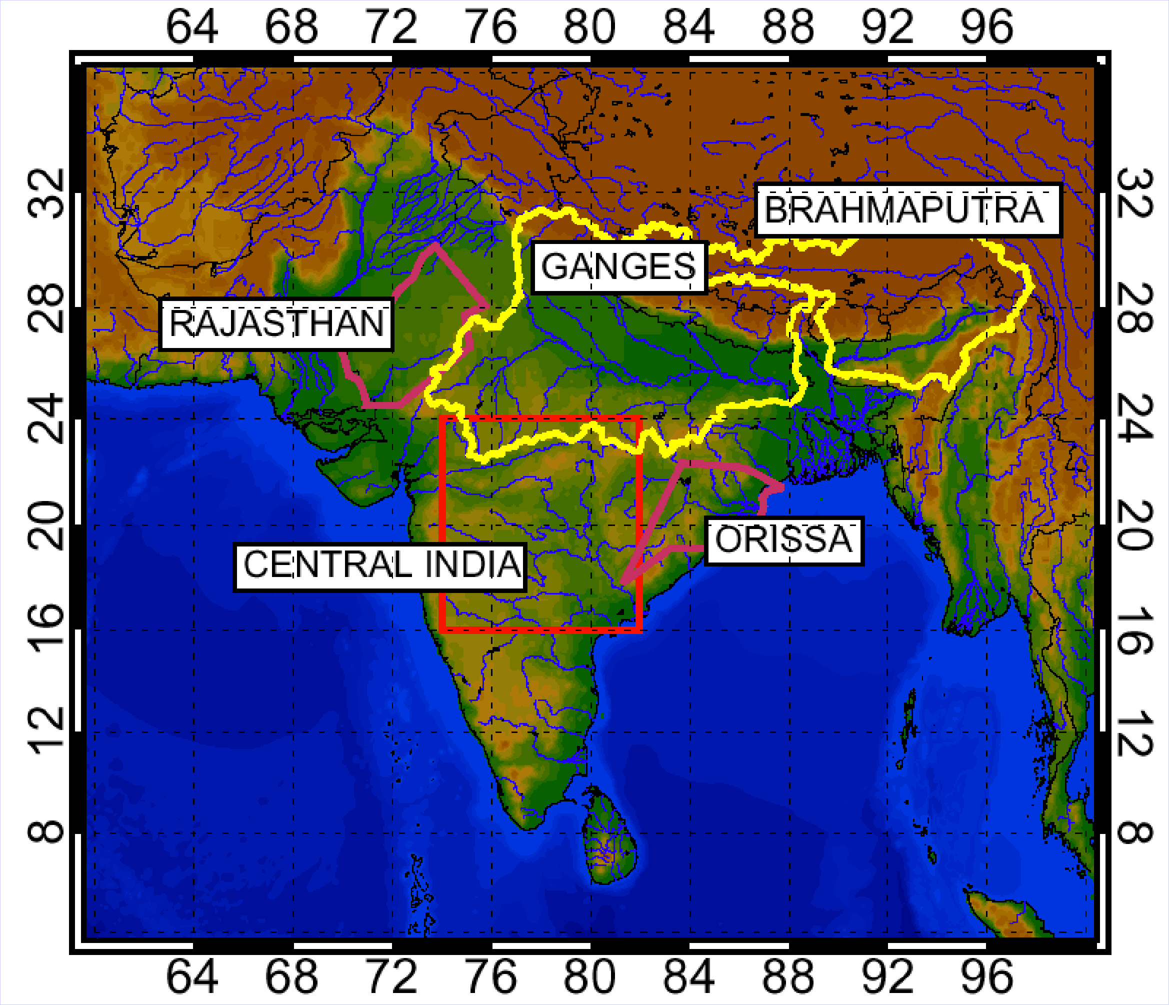
- We use wavelet analysis to determine the dominant bands, separate the data into these bands and then use simple linear regression in each band. Recombination provides the forecast

- Method is <u>easy to use</u> and produces credible 20-30 day forecasts of regional and 5-day mean precipitation

- Choice of the predictors: These are physically based and strongly related the MISO evolution (identified from diagnostic studies).

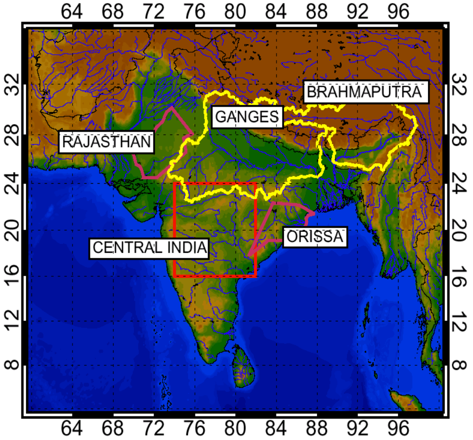
Webster and Hoyos (BAMS: November 2004)

Predictands

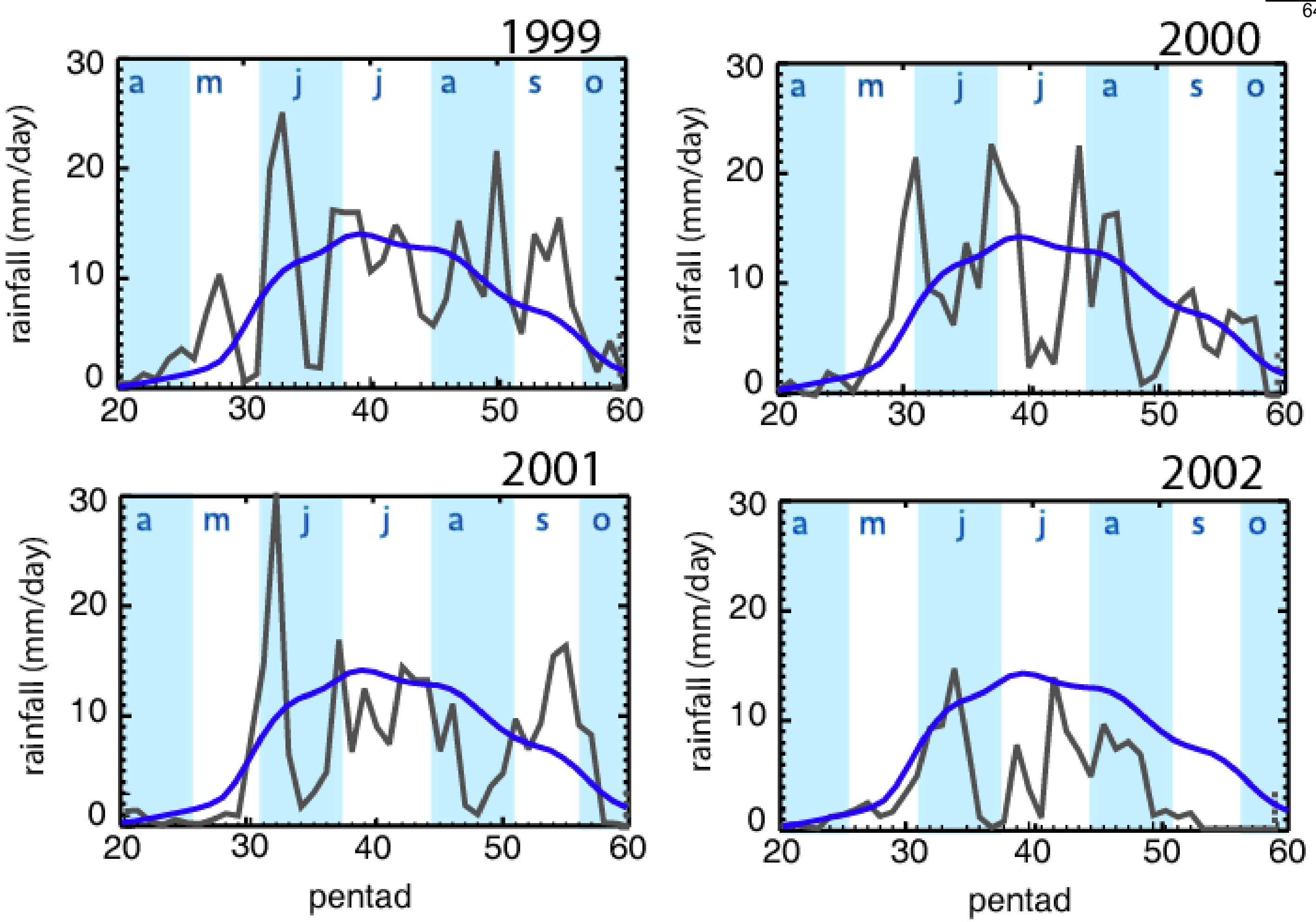


1. Central India Precipitation. 2. Regional Precipitation
3. River Discharge

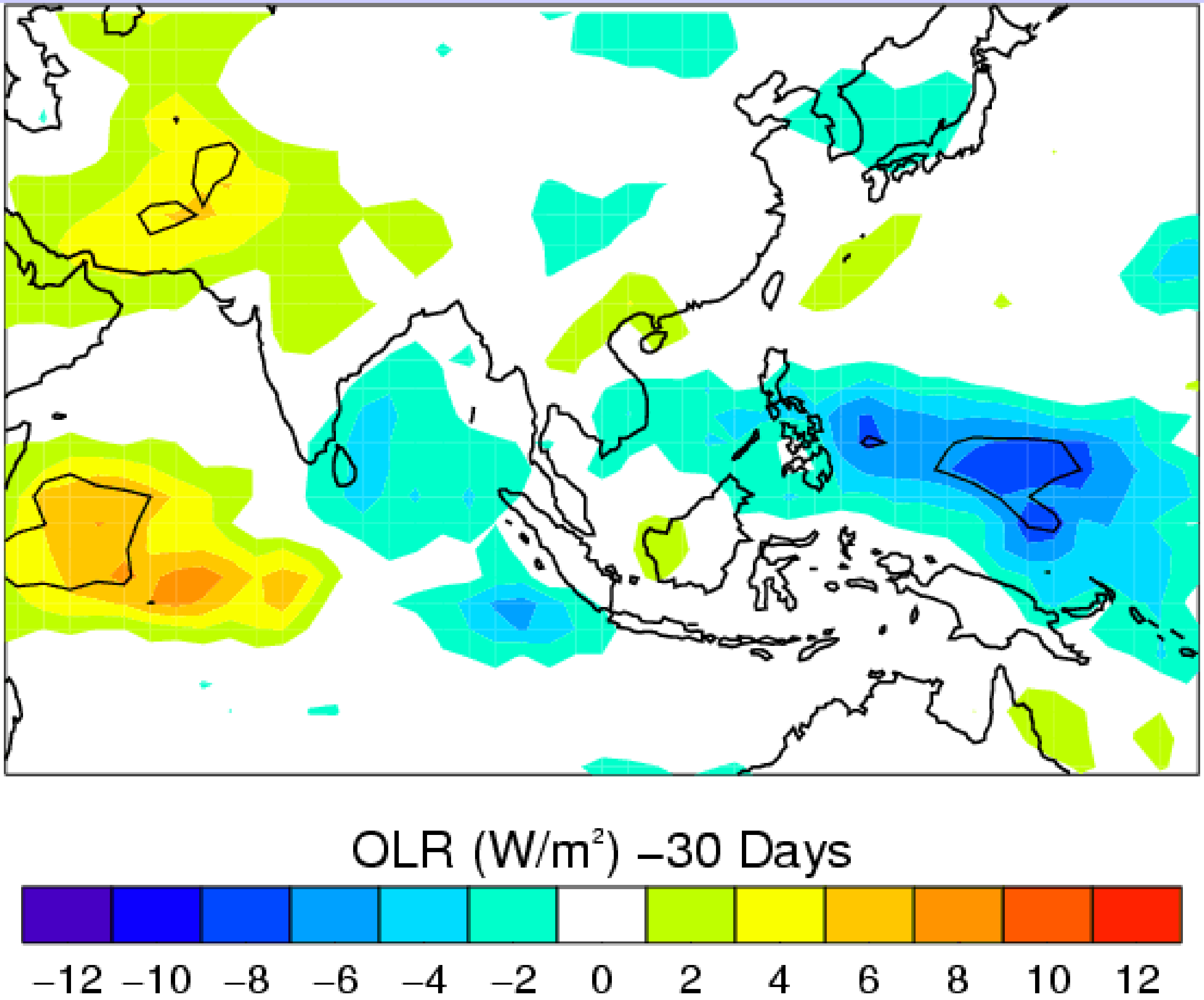
Forecasting Intraseasonal Variability



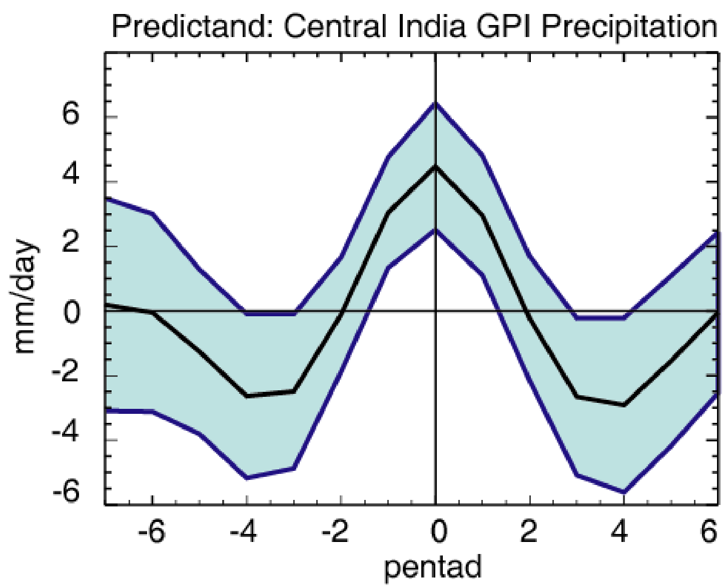
(b) Central India pentad GPI rainfall for 1999-2002



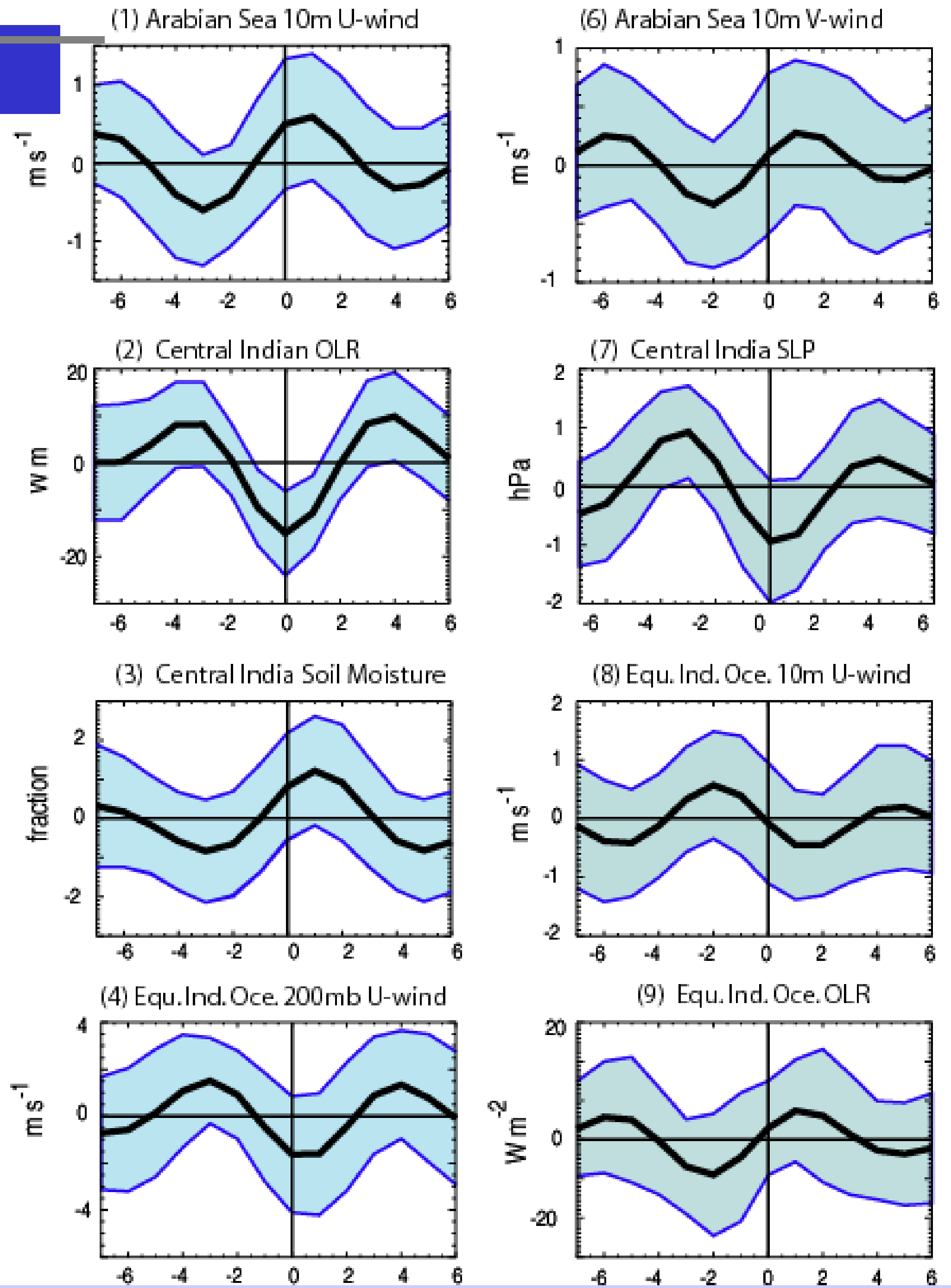
Making use of slow manifold for empirical forecasting



Composites of Predictors

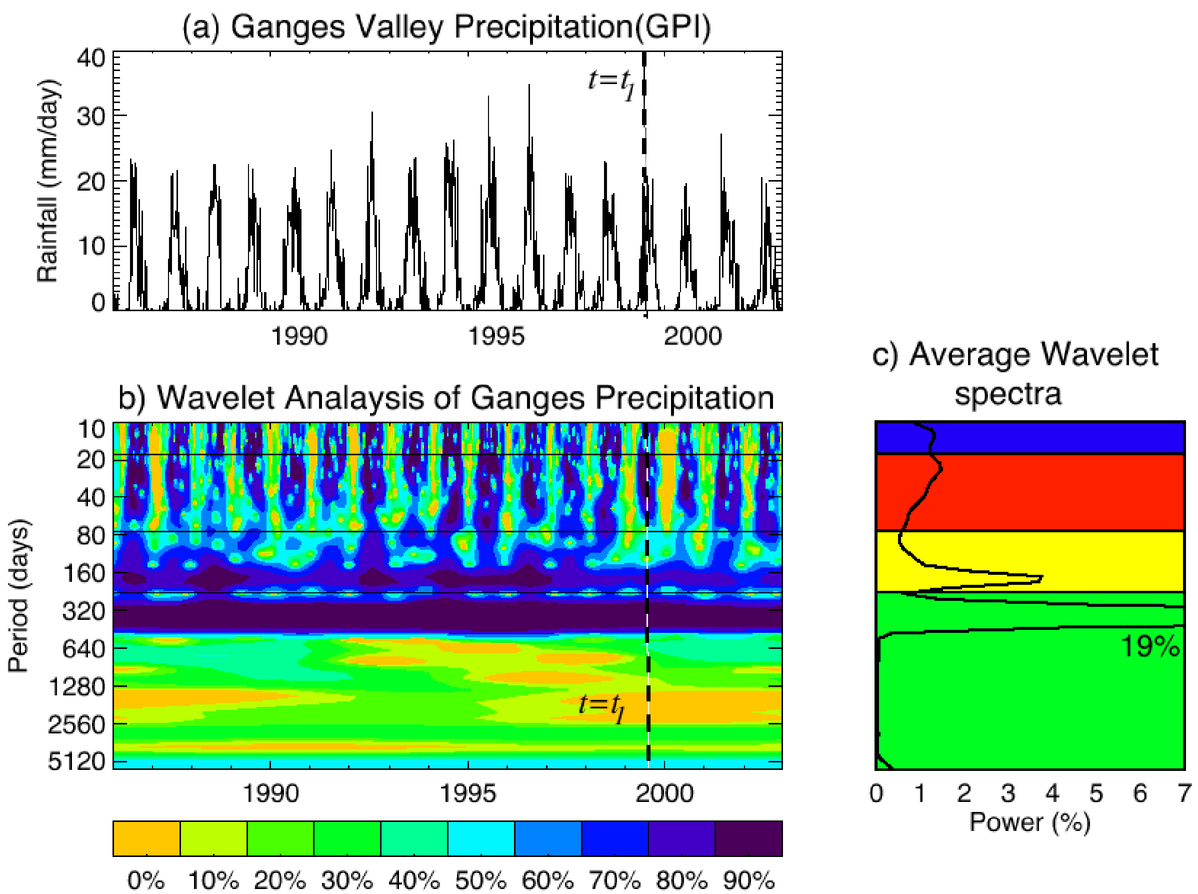


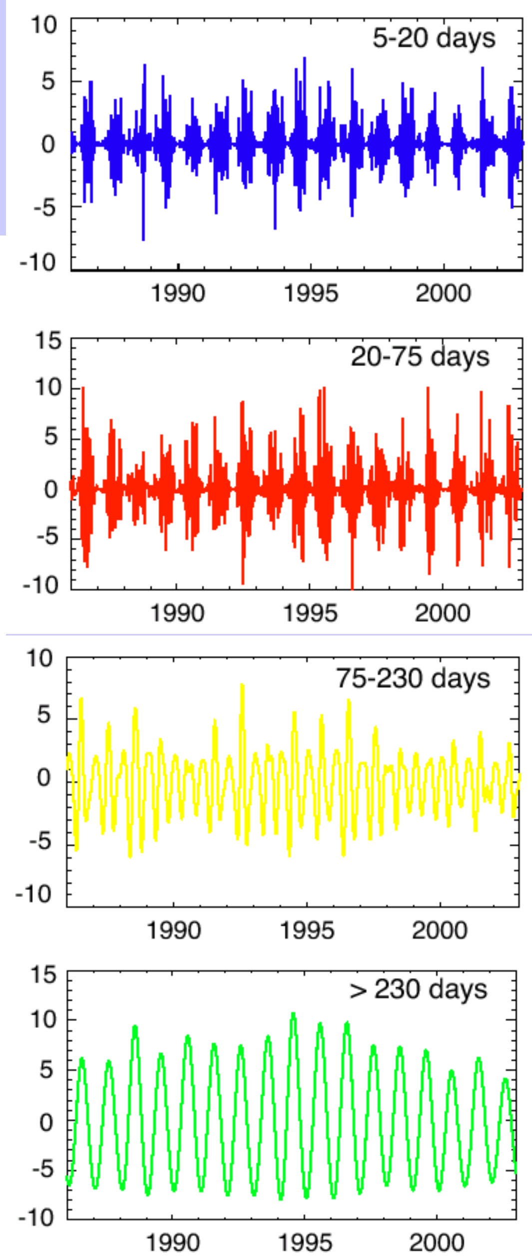
Predictors covariation with predictand.



Statistical Scheme: Wavelet Banding

Statistical scheme uses wavelets to determine spectral structure of predictand.

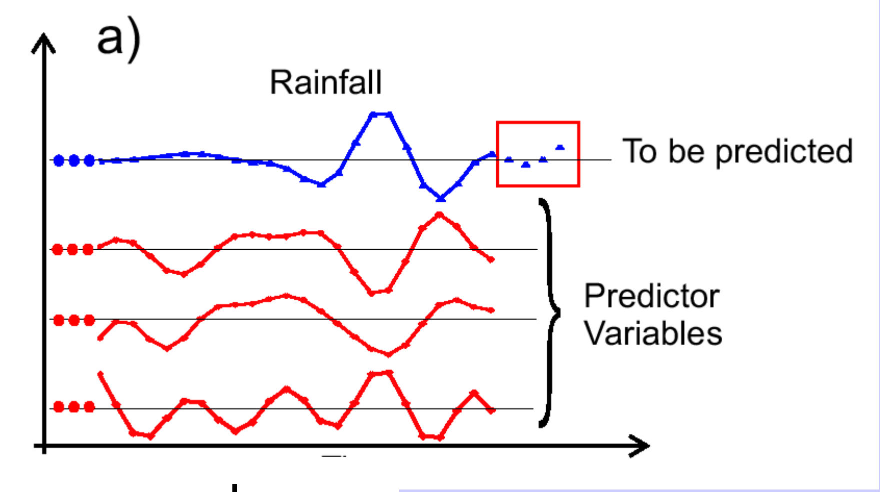


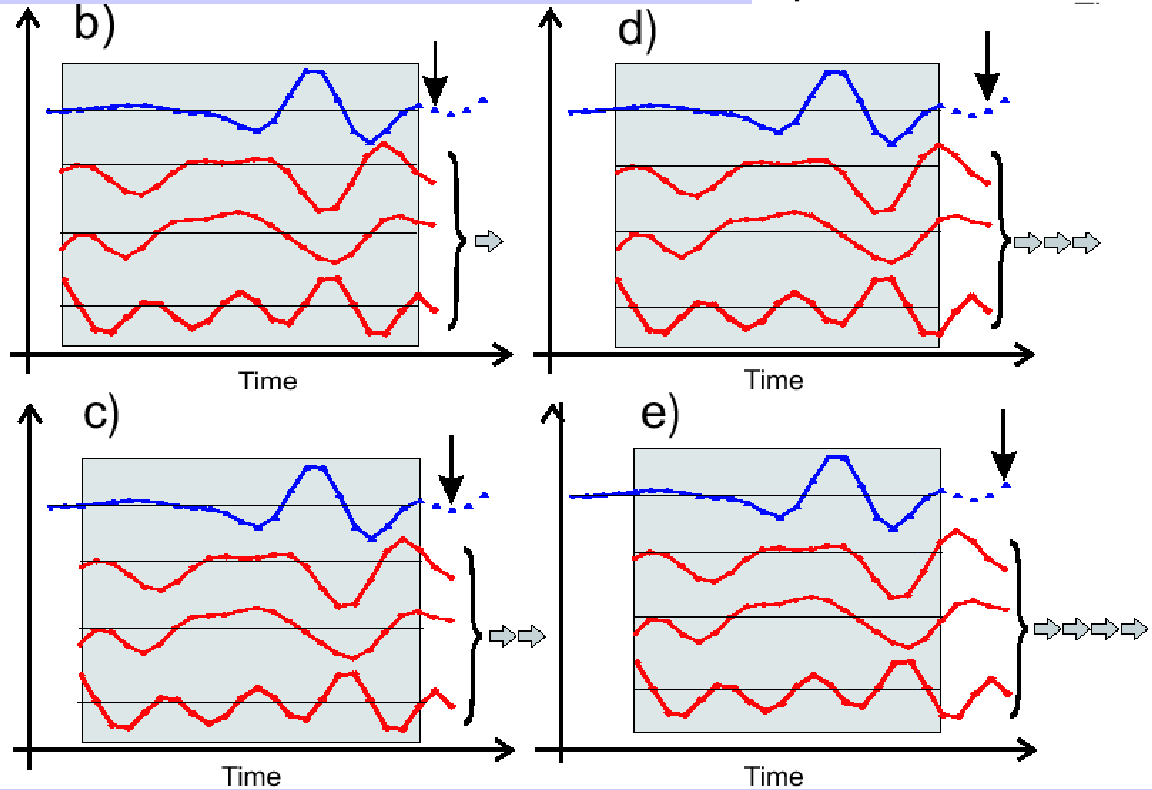


Based on the definition of the bands in the predictand, the predictors are also banded identically

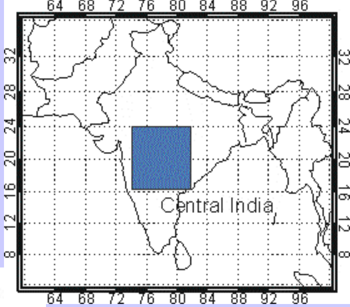
Statistical Scheme: Regression Scheme

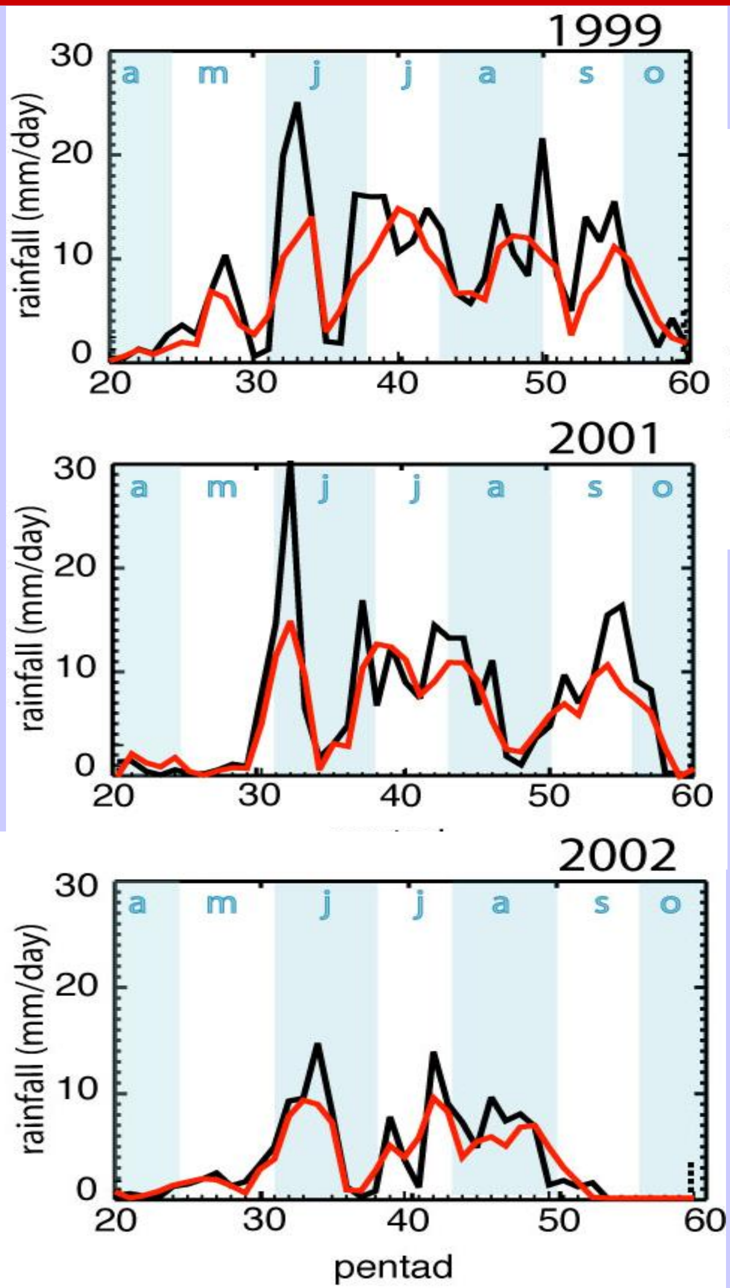
Linear regression sets are formed between predictand and predictor and advanced in time.

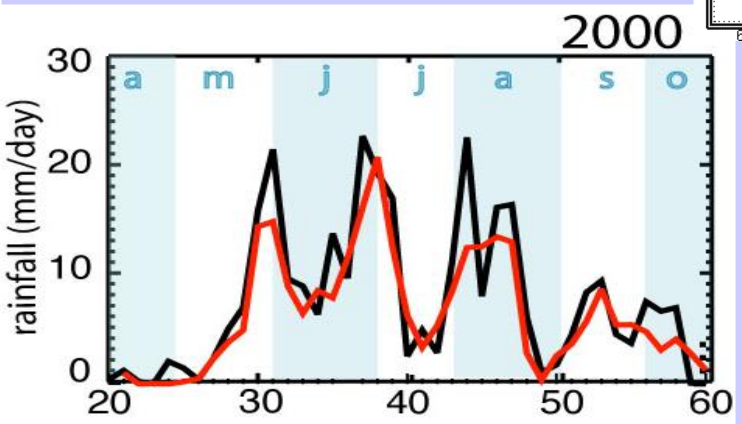


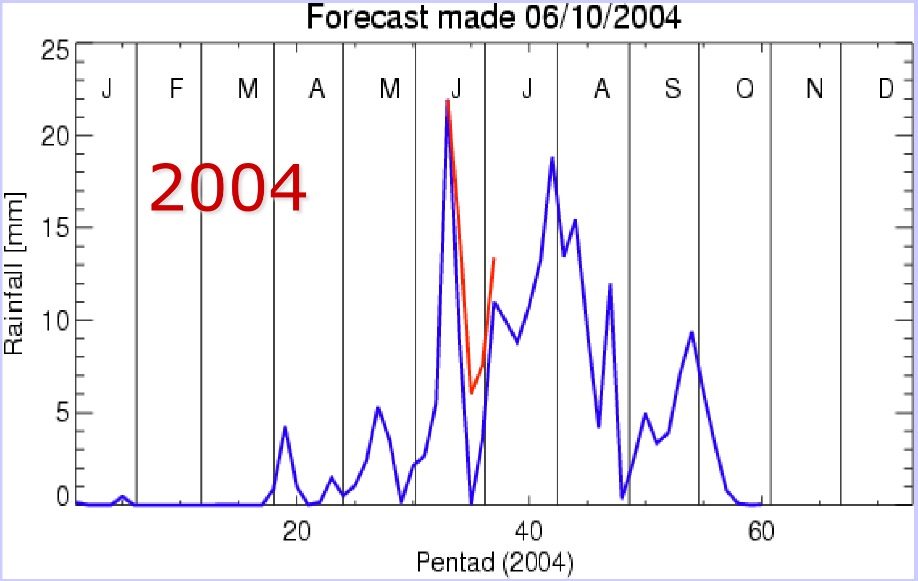


20-day forecasts for Central India

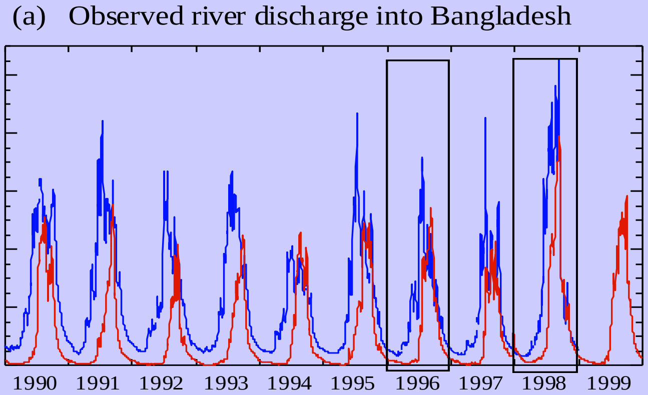


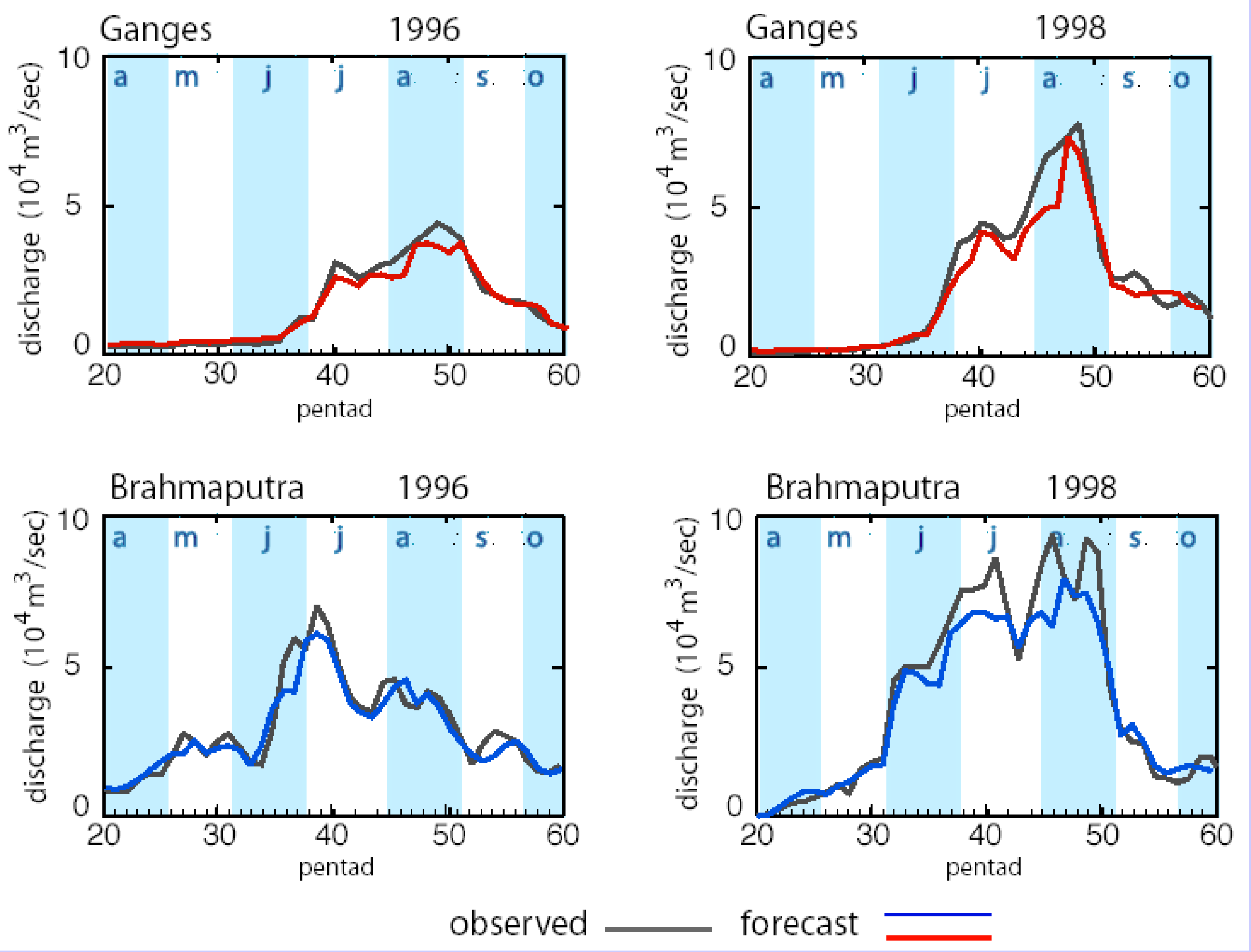


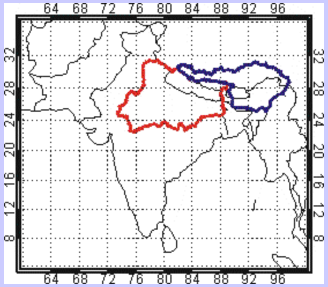




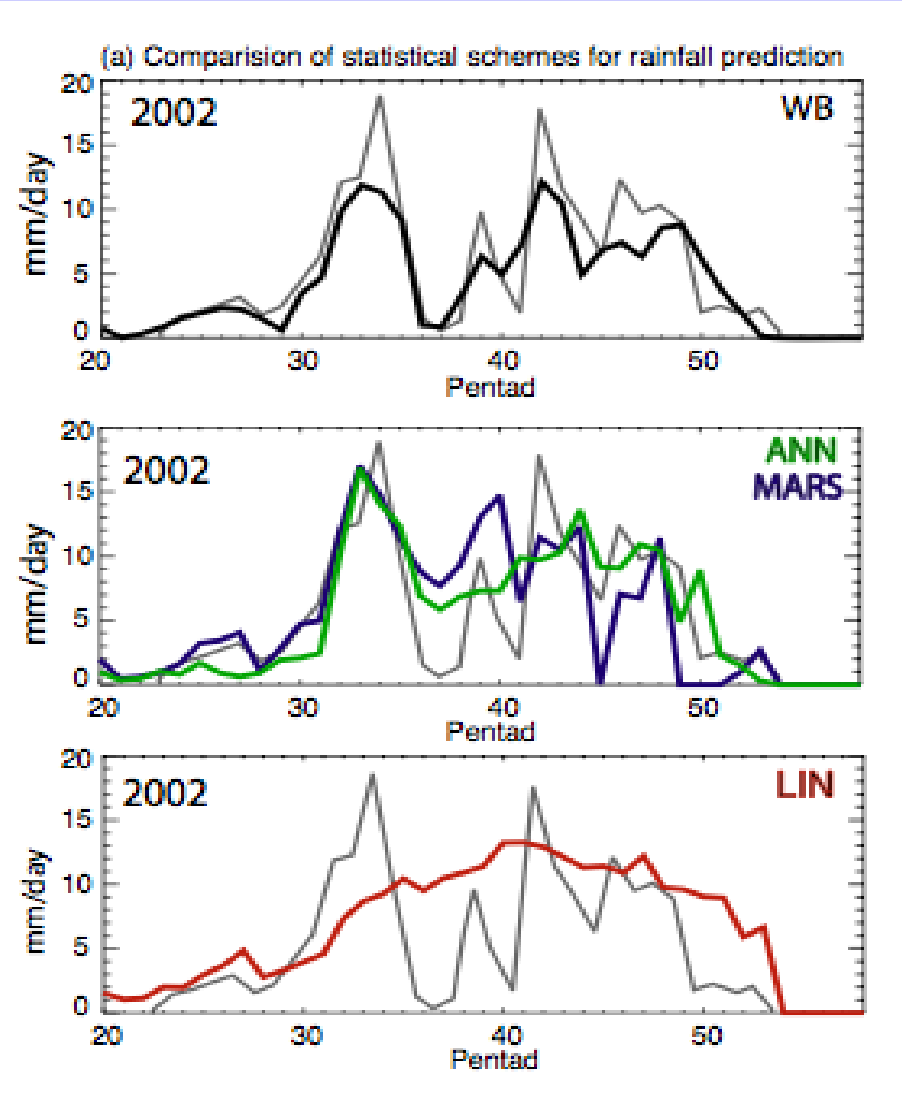
Brahmaputra and Ganges Discharge into Bangladesh







Why does the empirical scheme work?

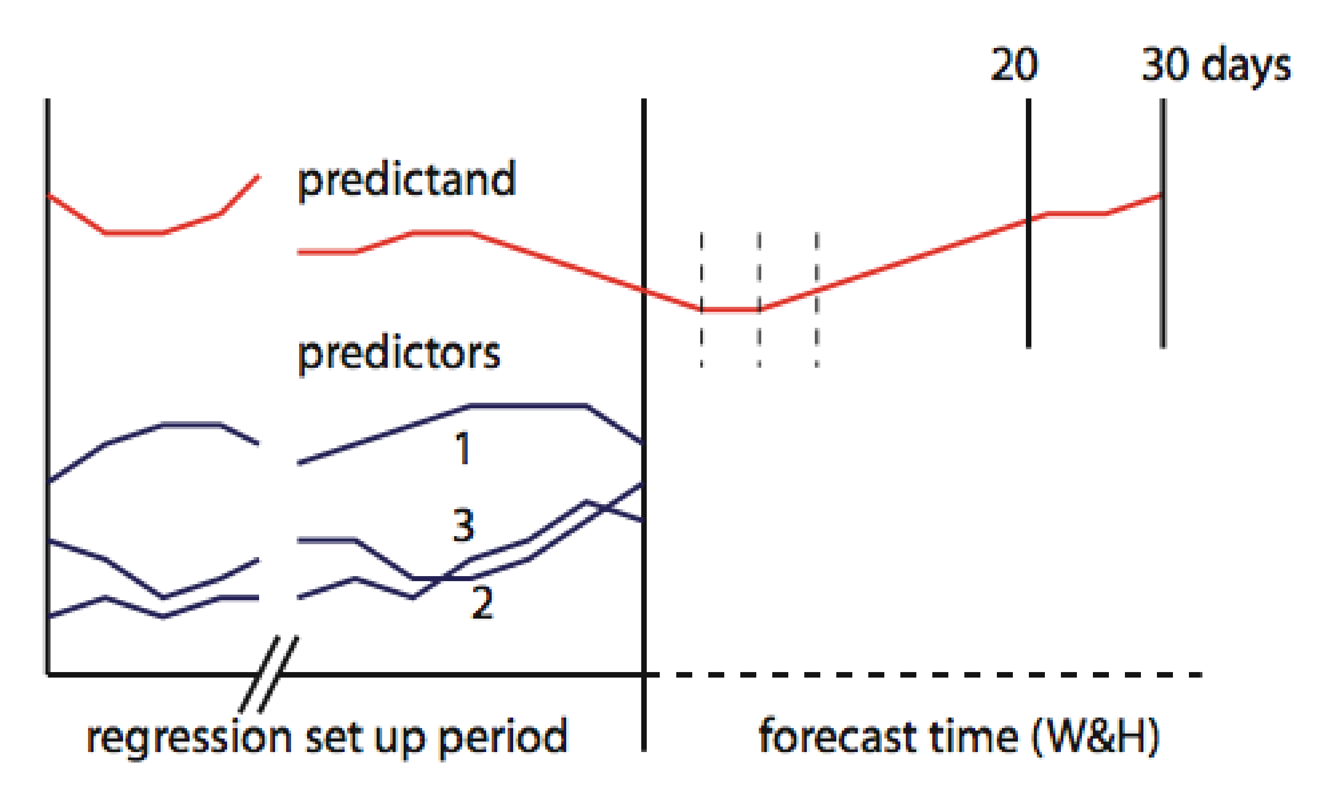


- Choice of predictors is very important: must be physically based and related to the predictand
- But, same predictors with sophisticated regressions techniques (ANN, MARS) leads to degradation of forecast relative to WB
- Key factor is separation of spectral bands which “protect” the intraseasonal band from cascading errors
- Can we use this technique to improve numerical models?

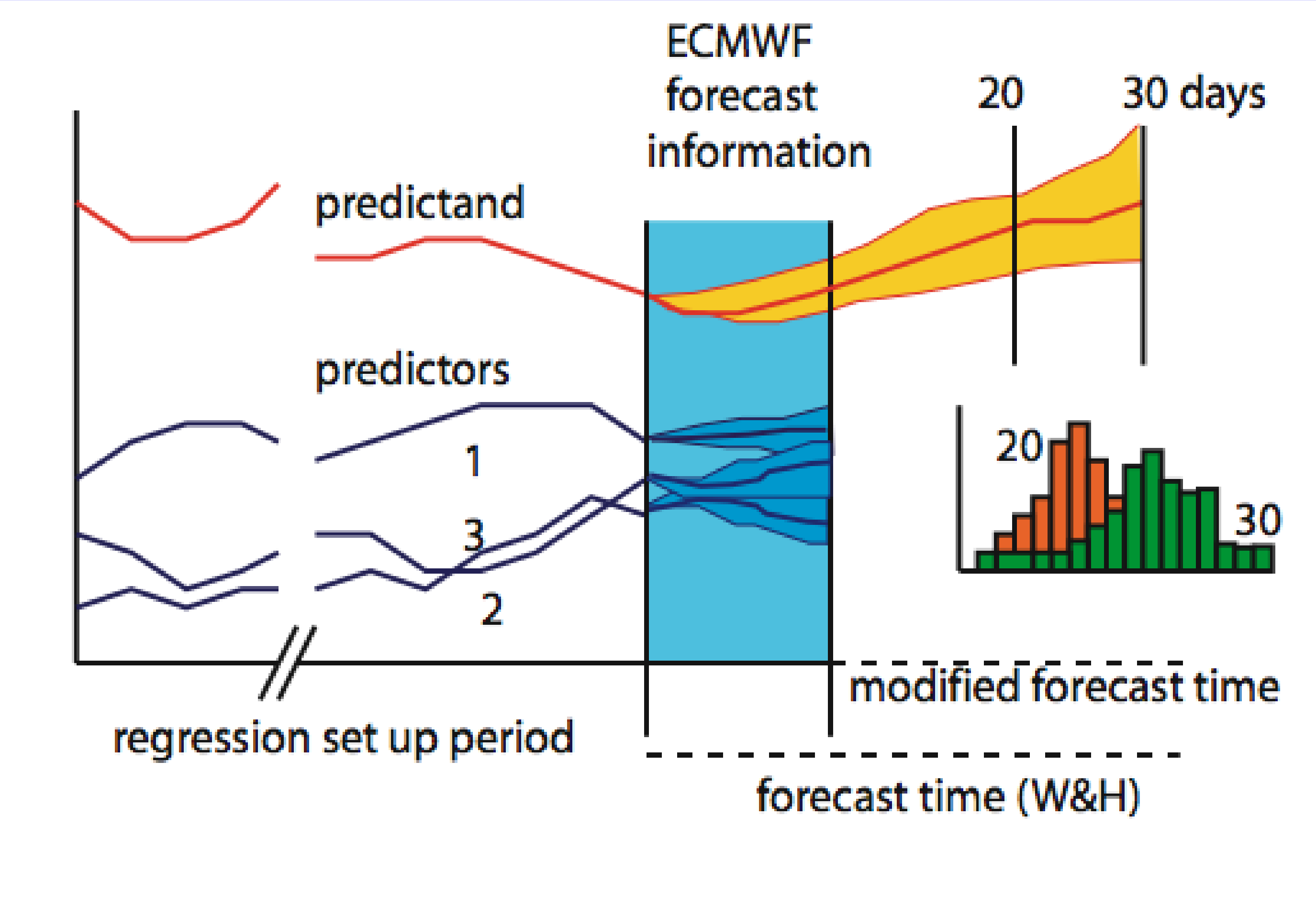
Modifying the Bayesian priors

- Currently, the Bayesian priors of the WB technique are the conditional relationships between the predictors. Protected by banding, the system works well.
- But we would like to inject future (and independent) information into the system to modify the Bayesian priors.
- The information we will use are forecasts of the predictand and predictors as given by the 51 member ensembles of the ECMWF operational model
- Such data will provide a 51-member suite of an addition 2 lags (2x5 days) extending the regression chains into the future.
- It will also render the 20-30 day forecasts probabilistic.

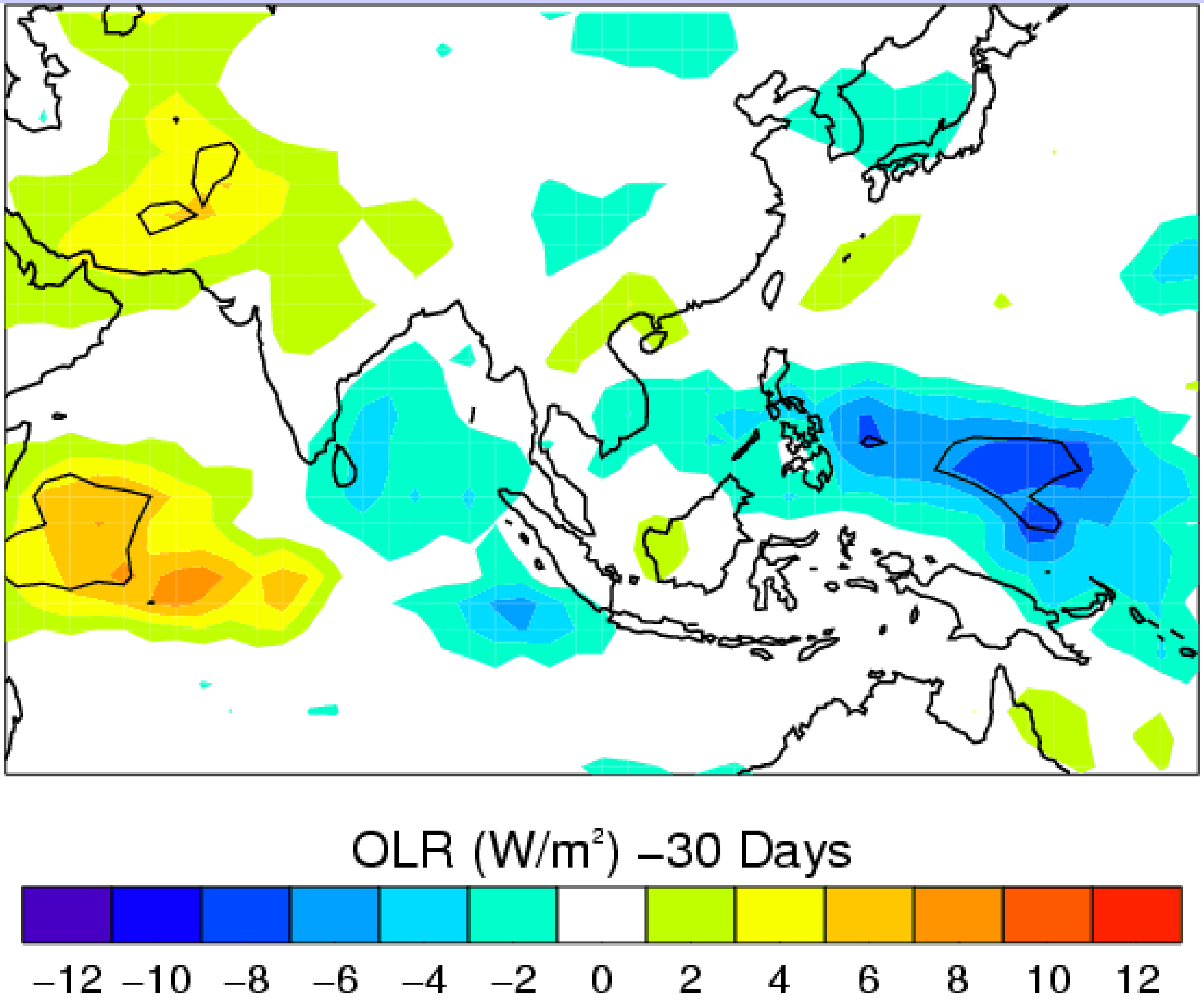
Original W&H (2004) schema used for each wavelet band



Proposed modification to modify Bayesian priors using ECMWF ensemble forecasts



Making use of slow manifold for modeling ISO



Active phases of the monsoon commence near the equator and propagate northward (and southward) across South Asia.

A new look at numerical modeling

- Convective parameterization continues to be a problem and is a likely culprit for ISO degradation.
- Perhaps cloud resolving models and/or higher resolution simulations will eventually lead to better extended operational forecasts. Perhaps the quest for seamless integration is still somewhere in the future.
- Thus, to move ahead now and provide forecasts where they are needed, we have to think a little differently.

A new look at numerical modeling

- The quest is to maintain the large-scale convective signal whilst reducing the convective parameterization errors.
- We attempt to do this by adapting the banded wavelet protection scheme to the ECMWF coupled climate model.
- Here we show some initial results.

A new look at numerical modeling

- The quest is to maintain the large-scale convective signal whilst reducing the convective parameterization errors.
- We attempt to do this by adapting the banded wavelet protection scheme to the ECMWF coupled climate model.
- Here we show some initial results.

CAUTION: The Director of WCRP has issued a warning that modeling purists may be offended by the following material. It is recommended that graduate students and those without tenure refrain from viewing the following 8 slides!

Why not just use empirical forecasting techniques?

Empirical forecasts appear to do very well in forecasting the MISO! Why bother with numerical models?

- Empirical models are "local" and provide a forecast for just one predictand (e.g., precipitation over Central India). For a different predictand, a different set of predictors have to be developed
- Numerical models provide consistent global fields of variables

“Slow Manifold Modeling” of Intraseasonal Variability: A New Approach

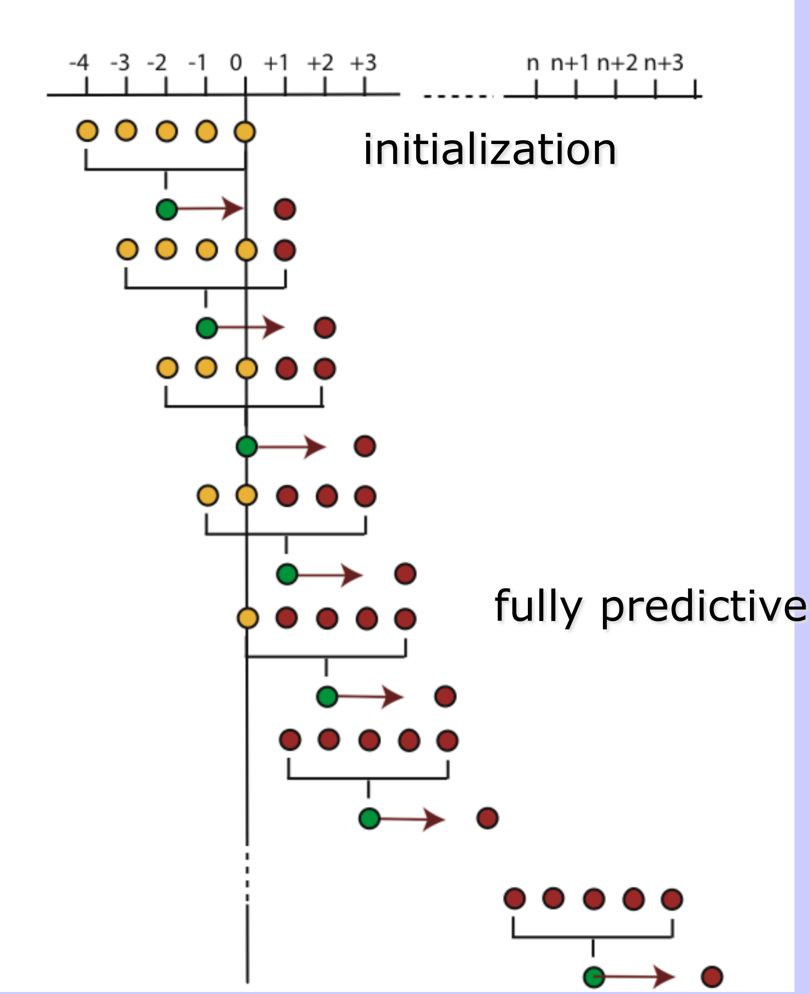
Hypothesis:

Separation of convective noise and slow manifold intraseasonal variability will increase 20-40 day predictability

Strategy:

Quell upscale destructive influence of convective parameterization error by “creeping” integration
Scale separation similar to the “wavelet banding” scheme of Webster and Hoyos (2004)

N=5 Modeling Schema



“Slow Manifold Modeling” of Intraseasonal Variability: Concept

(1) Hypothesis:

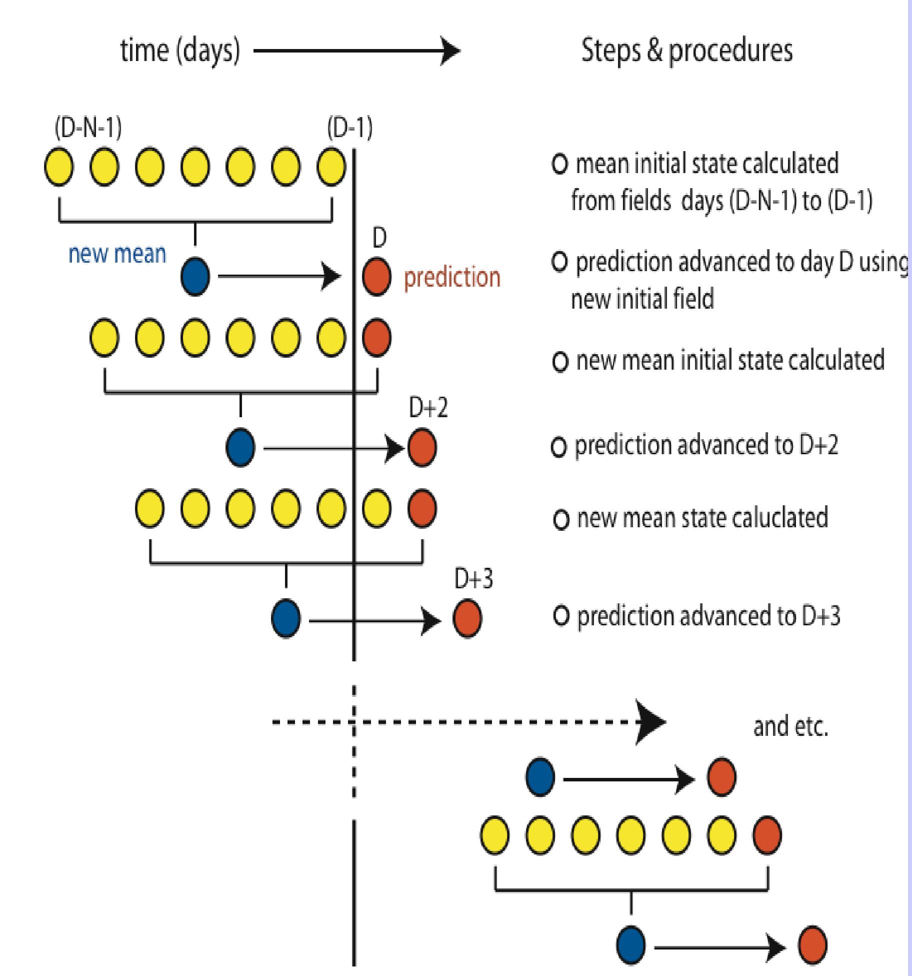
- Separation of convective noise and slow manifold intraseasonal variability will increase 20-40 day predictability

(2) Strategy:

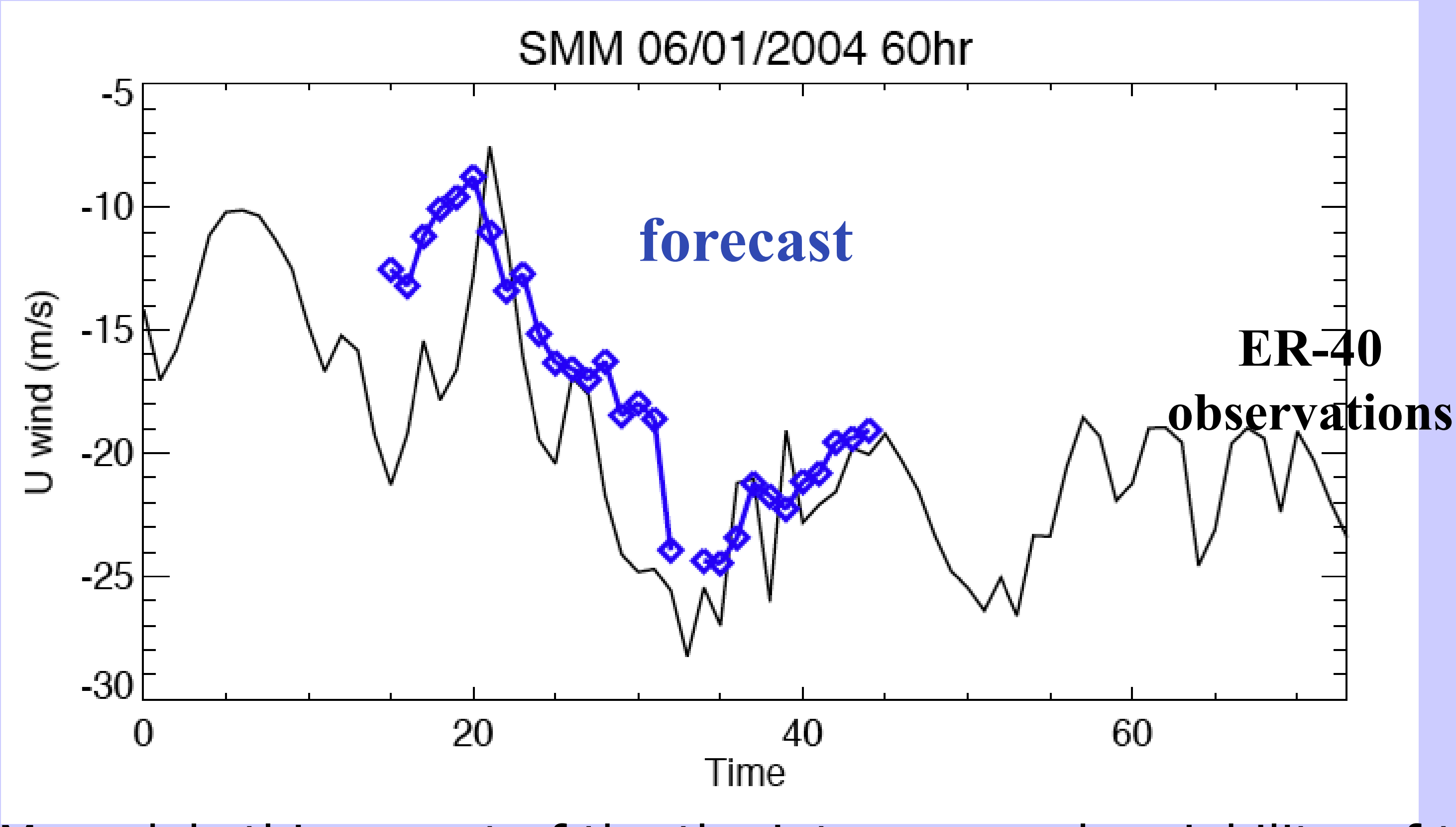
- Quell upscale destructive influence of convective parameterization error by “creeping” integration
- Scale separation similar to the “banded wavelet” scheme of Webster and Hoyos (2004)

(3) Status:

- Currently running experimentally at ECMWF



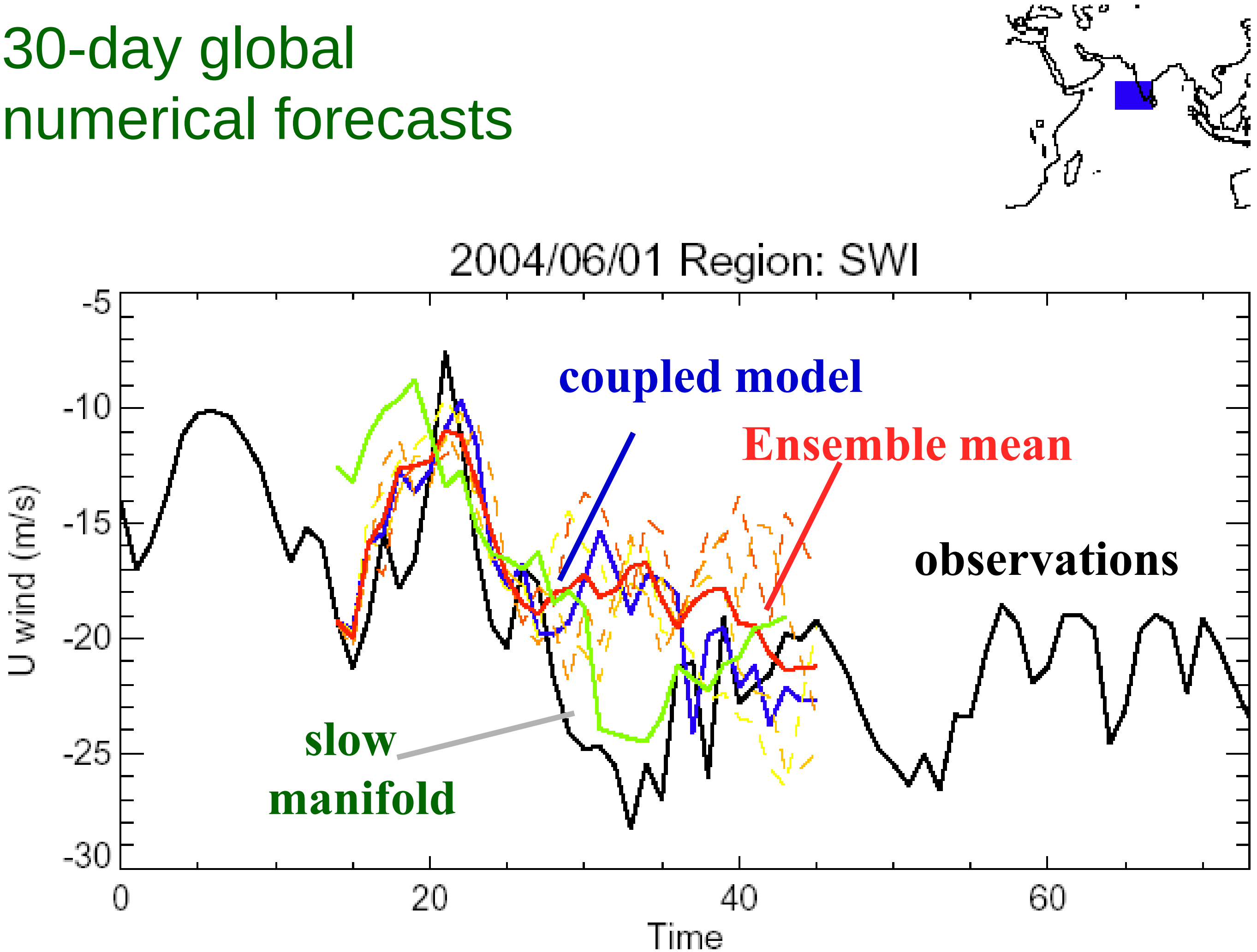
30-day forecast using SMM



SMM models this aspect of the the intraseasonal variability of the monsoon quite well. Field is 200mb wind field over southern India. This result uses N=7

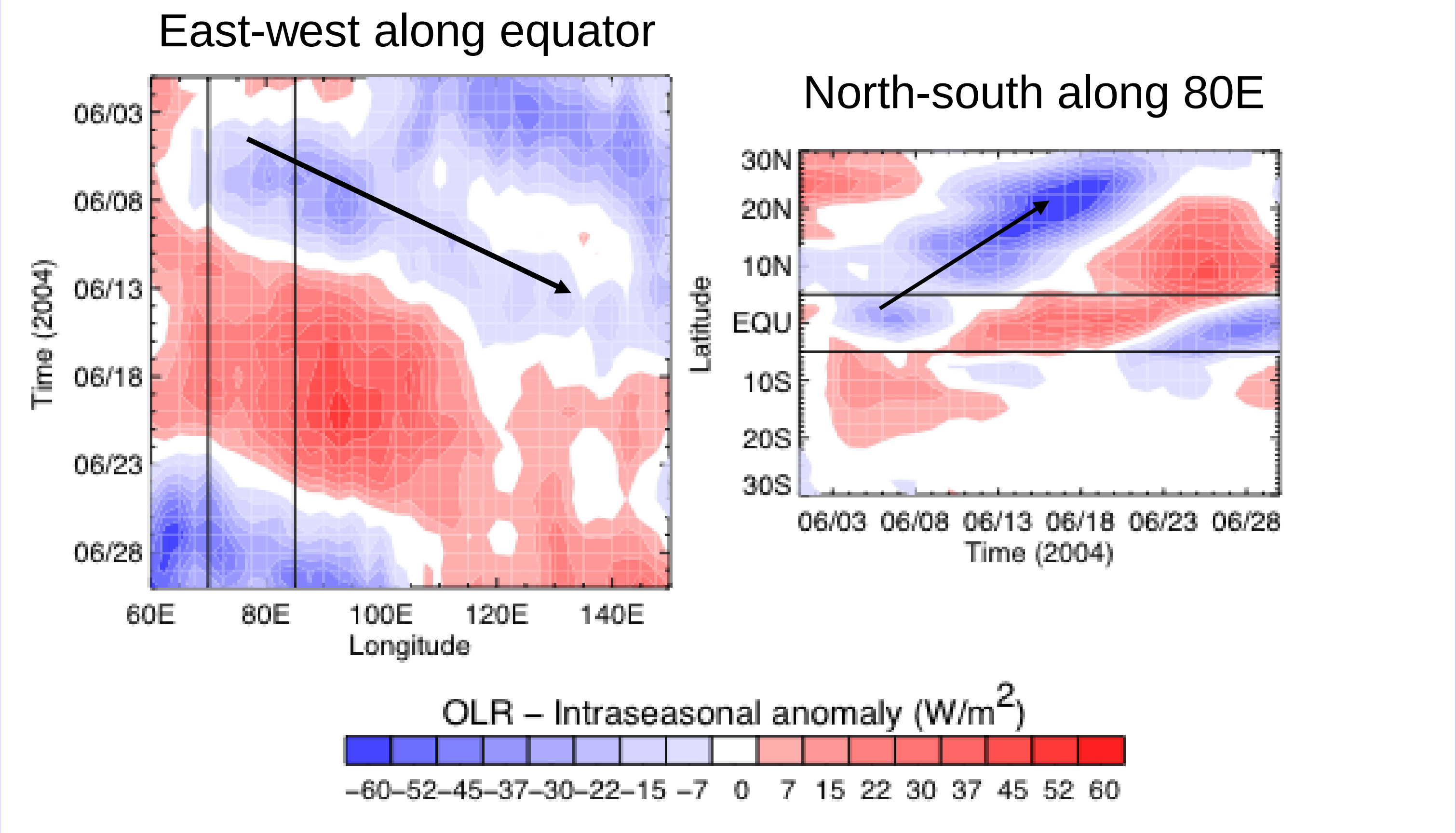
Comparison of Slow Manifold Model with coupled climate model

30-day global numerical forecasts

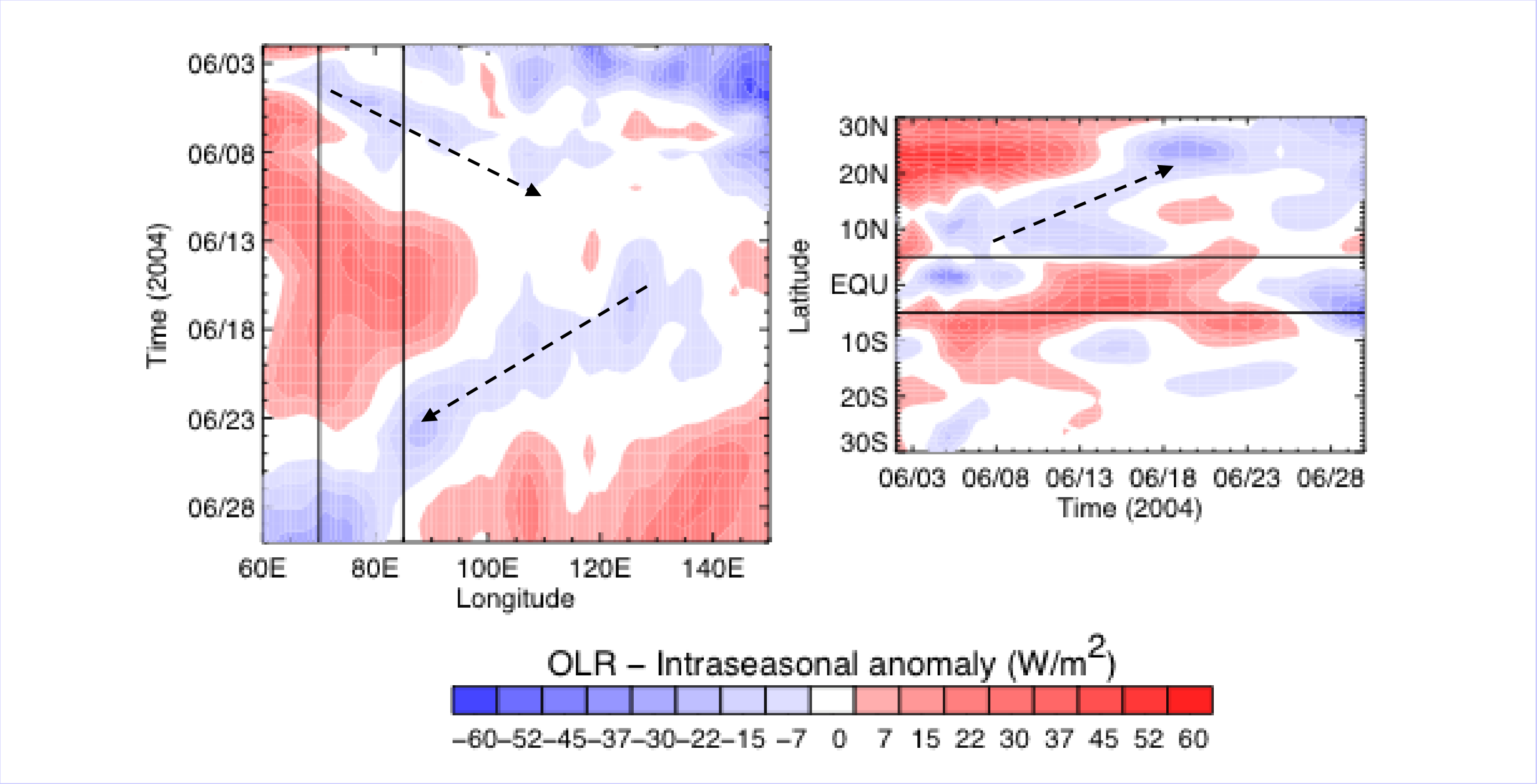


Slow Manifold technique provides more accurate longer term prediction

The CDC OLR evolution during May 2004 in Indian Ocean

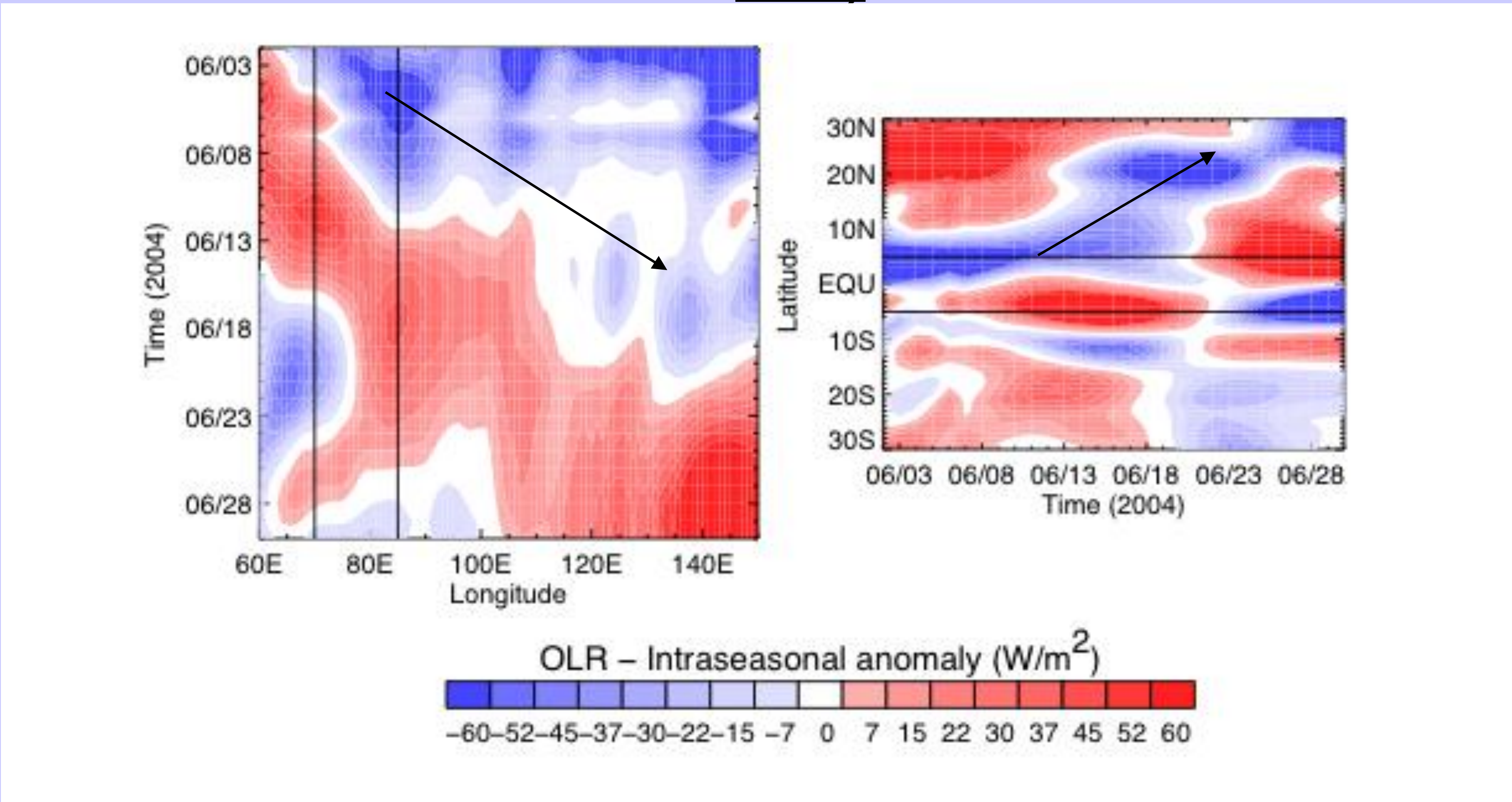


OLR of Ensemble mean of EC-CM



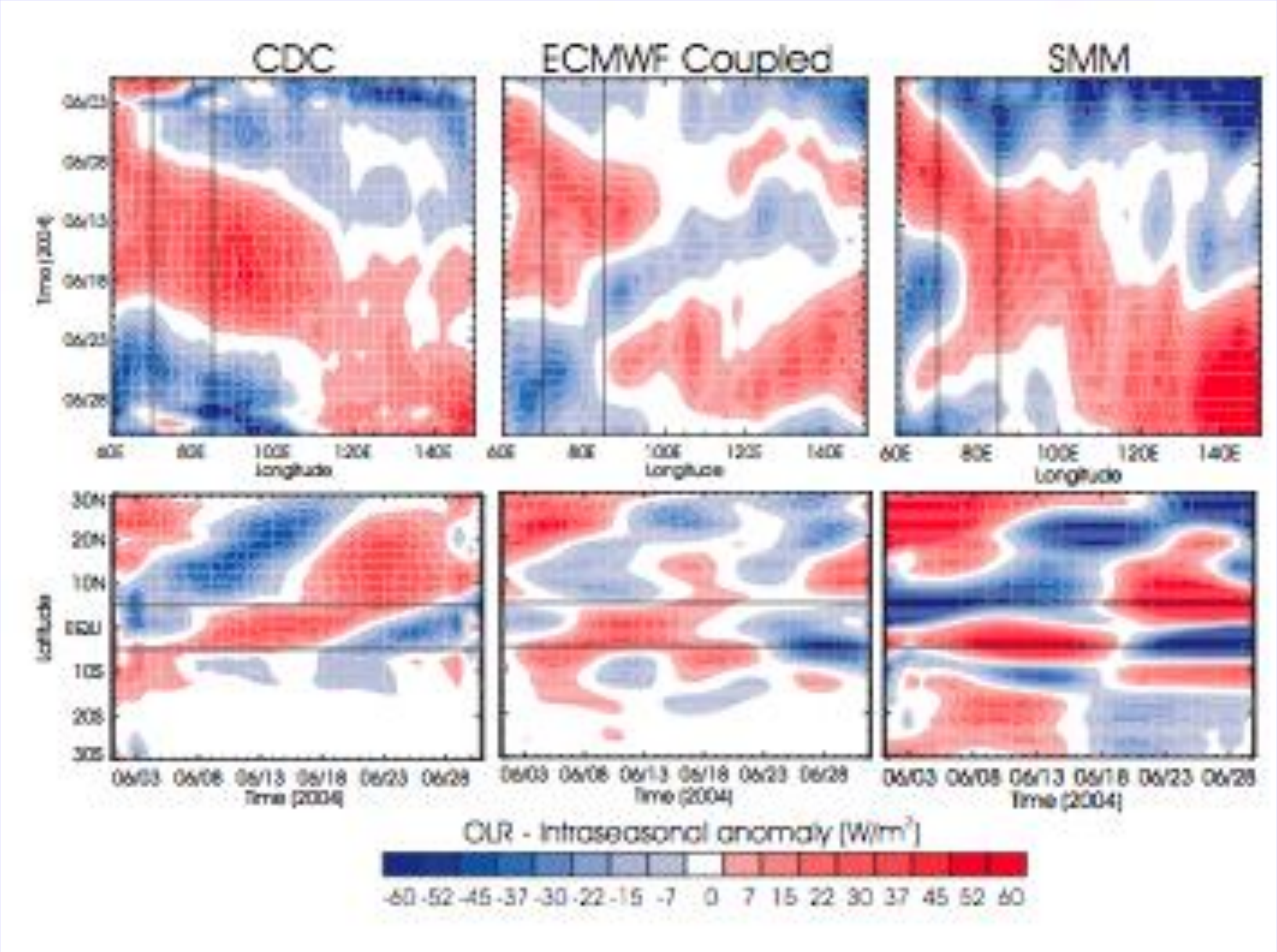
Note that the precipitation events rapidly loses identity as it propagates eastward and is replaced by a mode moving towards the west.

OLR of SMM (I.e., the EC-CM with the SMM modifications N=5)



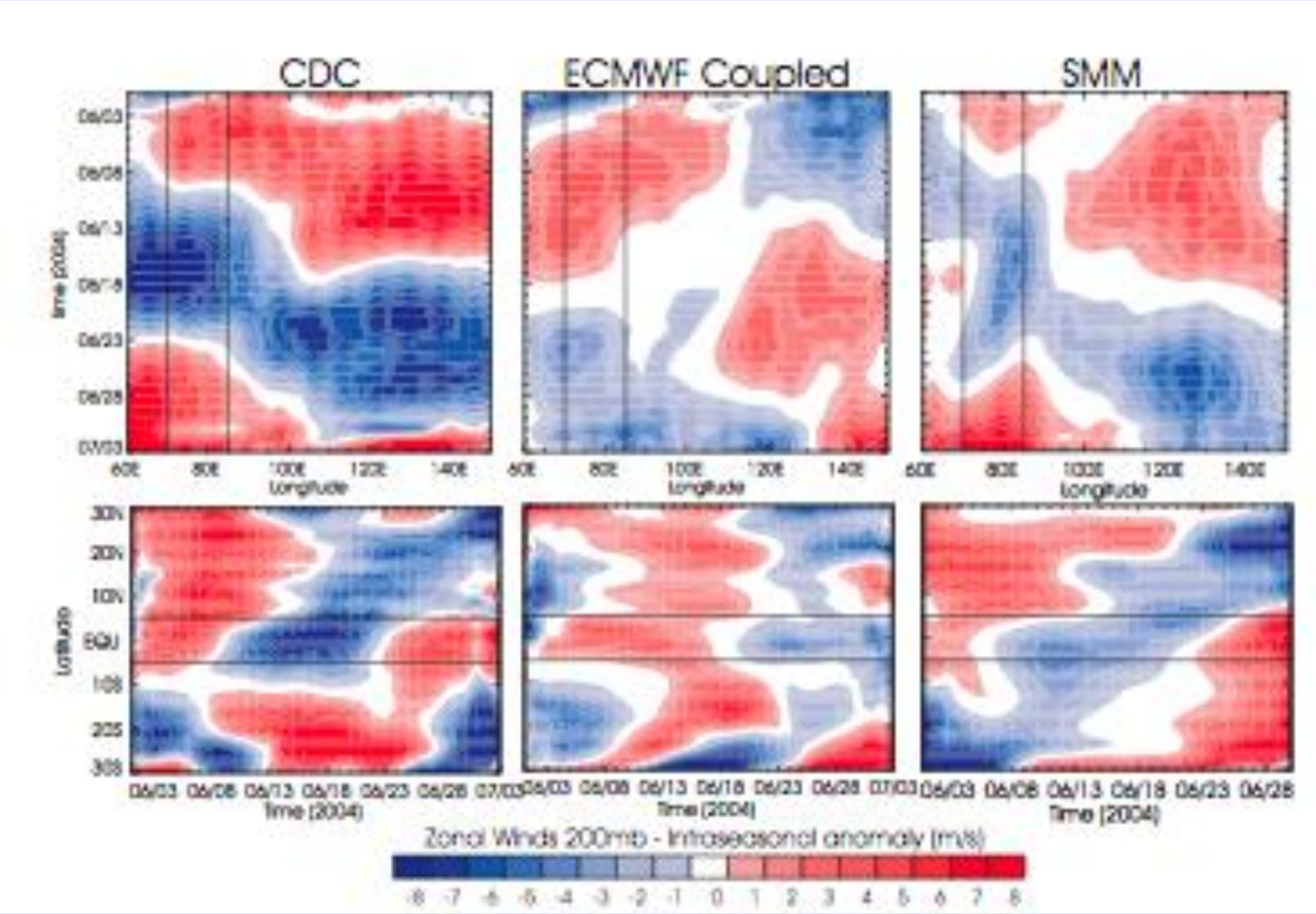
The SMM appears to hold the intensity and mode propagation direction of the monsoon ISO. The results are quite heartening but still much to do.

Comparison of observed, ECMWF model and SMM OLR: N=5, monsoon 2004



Hoyos and Webster (2007)

Comparison of observed, ECMWF model and SMM 200 mb U: N=5, monsoon 2004

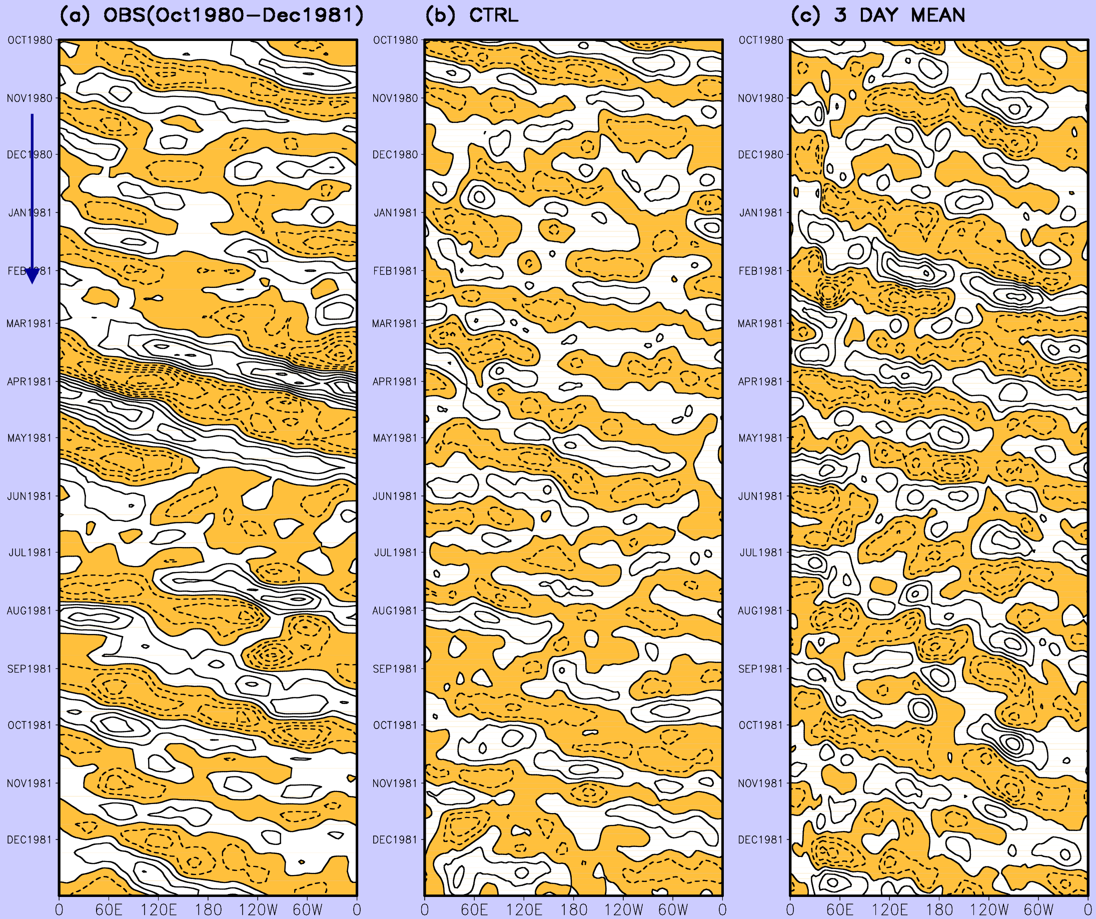


Hoyos and Webster (2007)

Corroborating Work for SMM

- Prof. In-Sik Kang SNU and Dr. Hye-Mi Kim (GT) have used the SMM scheme in collaboration with Georgia Tech for AGCM and CGCM simulations
- Using an N=3 format, they find:
    - Increase in magnitude of intraseasonal mode after extended integration
    - Reduction of high frequency error
    - Overall increase in predictive skill

Comparison of observed, control and SMM velocity potential evolution

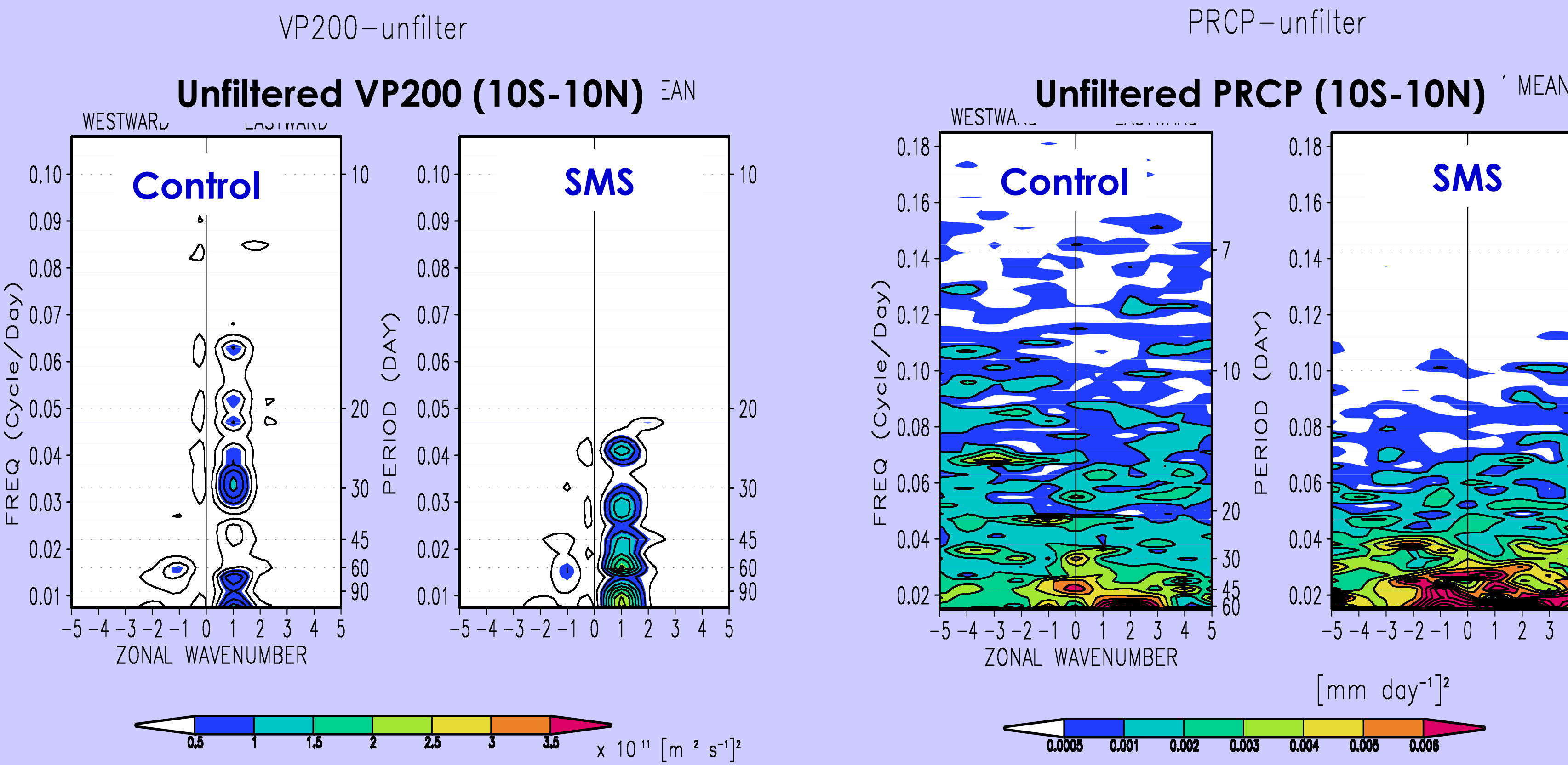


20-70 filtered velocity potential at 200 hPa between 10N-10S

SMM shows stronger amplitude and better phase of eastward propagating modes than control

(Courtesy H-M Kim Seoul National Univ)

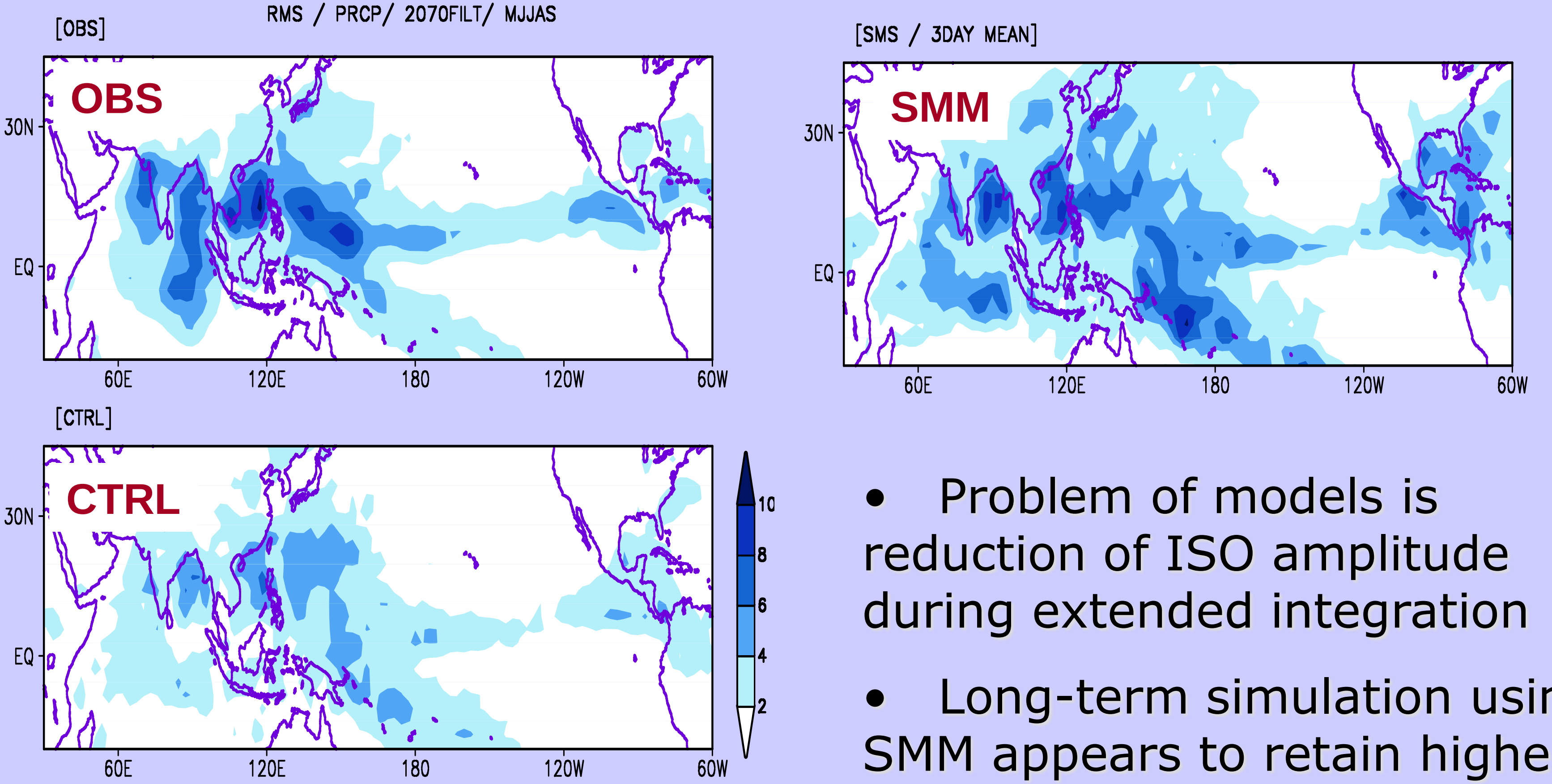
SMM-control space-time spectra (courtesy H-M Kim., SNU)



- In SMM, high frequency perturbations (<20days), strong in the control, decreases while low freq (40-70day) k=1 increases.

- Note strong low-frequency eastward modes retained at higher amplitude

Comparative ISO amplitudes of observed, control and SMM



- Problem of models is reduction of ISO amplitude during extended integration
- Long-term simulation using SMM appears to retain higher amplitude ISO signal.

Courtesy H-M Kim, SNU

Summary….. Empirical prediction

- Bayesian empirical modeling and Slow Manifold modeling both forecast monsoon intraseasonal variability with considerable skill

- For applications, the probability of an event occurring is an essential component of a forecast because it allows a cost/loss analysis to be made. Empirical scheme now probailistic.

- Bayesian model is regionally dependent and requires the creation of separate sets of predictors and regression sets for each situation (e.g., Indian monsoon and Australian monsoon will require different predictor sets)

Summary….. Numerical modeling

- Coupled models tend to lose MISO signature very rapidly because of rapid error growth emerging from convective parameterization:

- Statistical corrections to forecasts (nearest neighbor, quantile-to-quantile correction) can improve forecasts significantly

- Hybrid models (e.g., SMM) minimize error induced by convective params and seem improve prediction of the MISO

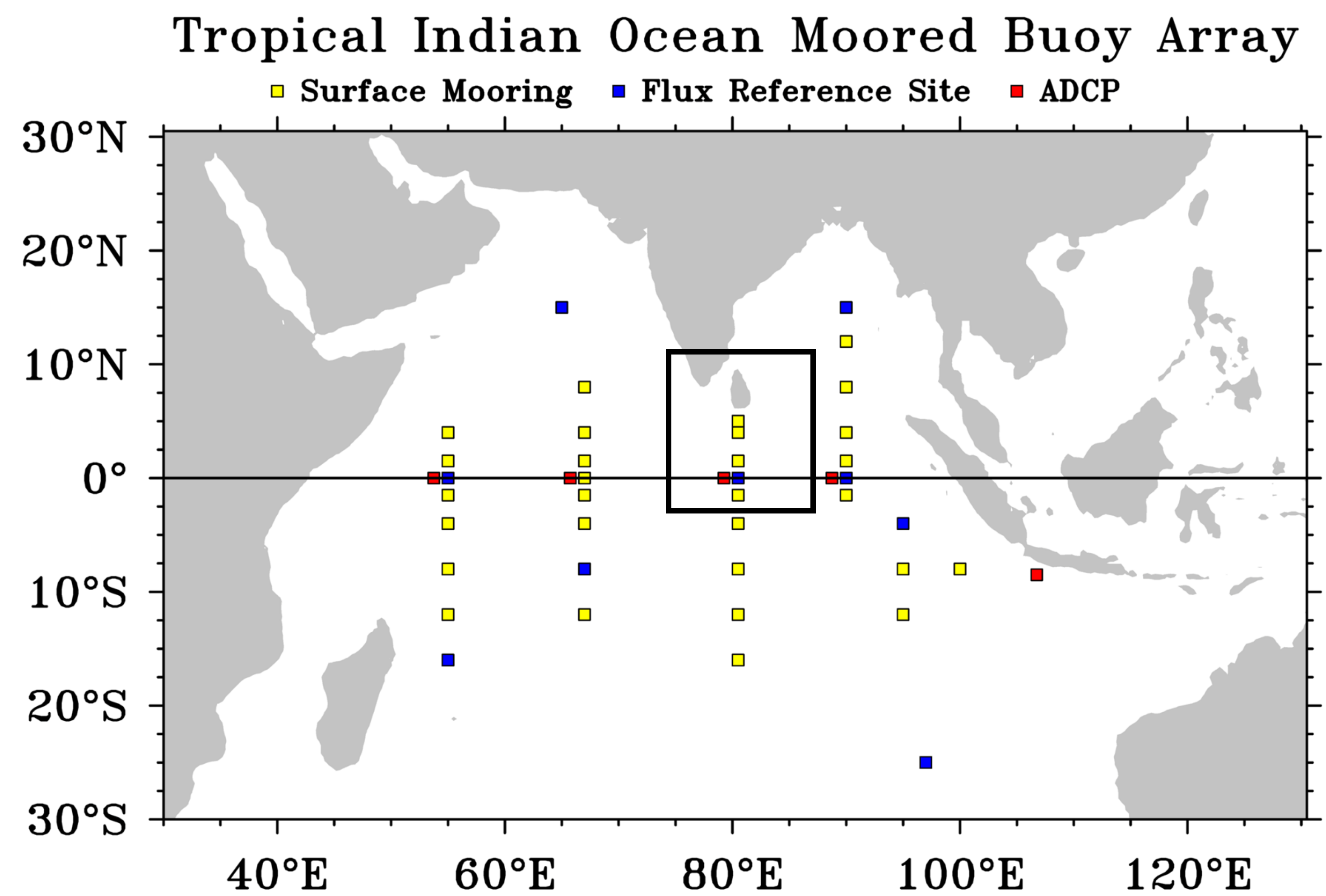
Why is the Indian Ocean a growth region for the ISO summer/winter?

What is special about the Indian ocean?

- On interannual times scales heat balance is “self rectifying”
- Largest annual cycle of heat flux in tropics
- Heat balance in atmosphere and ocean out-of-phase
- Equatorial westerlies most of year meaning that there is no equatorial upwelling with basic flow
- How does the summer hemisphere cool? Evaporation and mixing but also ISO performs major “ventilation”
- Equatorial western Indian ocean atmosphere extremely stable

Can these factors explain prominence of equ IO in ISO morphology?

Excellent opportunity to examine these issue with buoy array and proposed DYNAMO experiment



IO DJF

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TIFF (Uncompressed) decompressor
are needed to see this picture.

IO JJA

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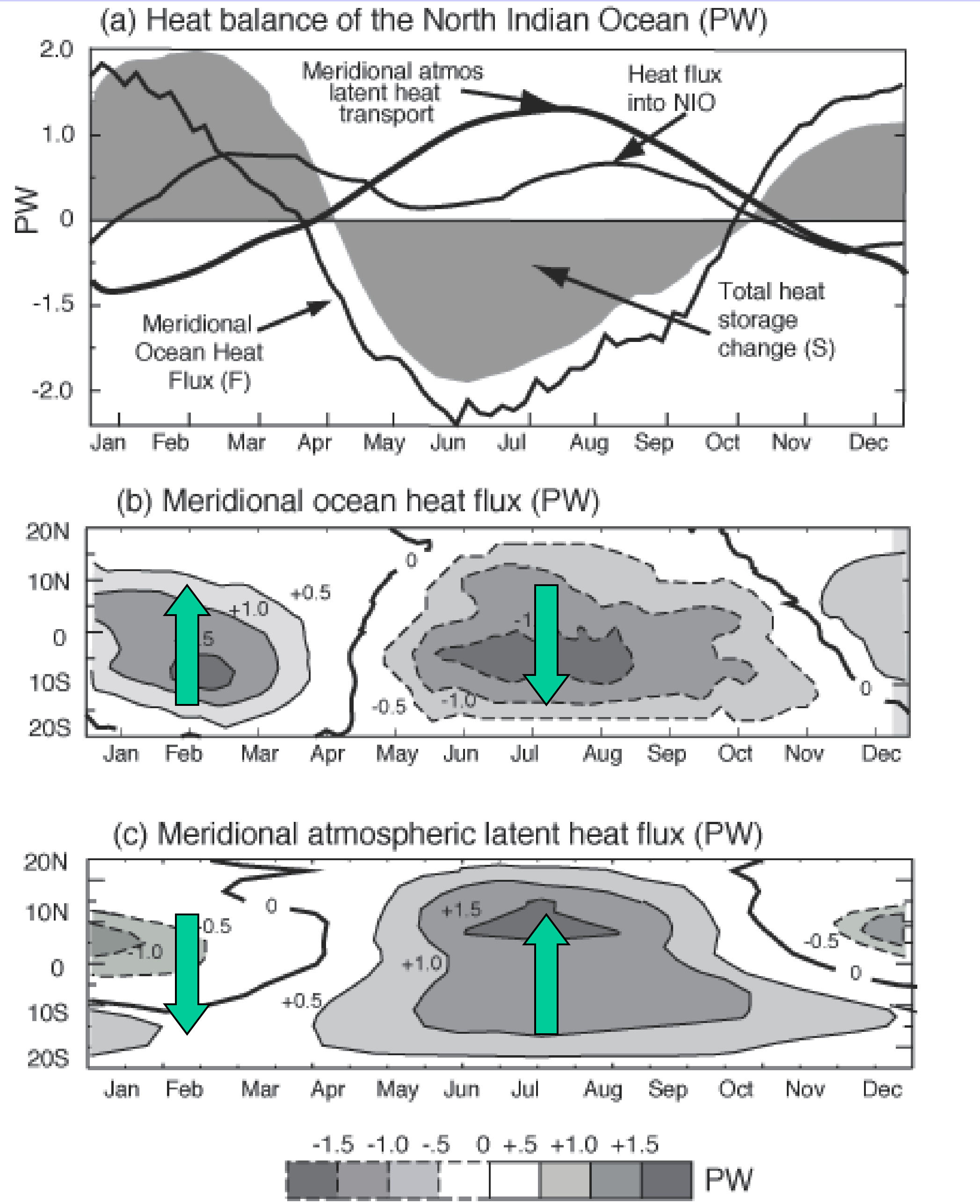
Annual Cycle of North Indian Ocean and Latent Heat Flux



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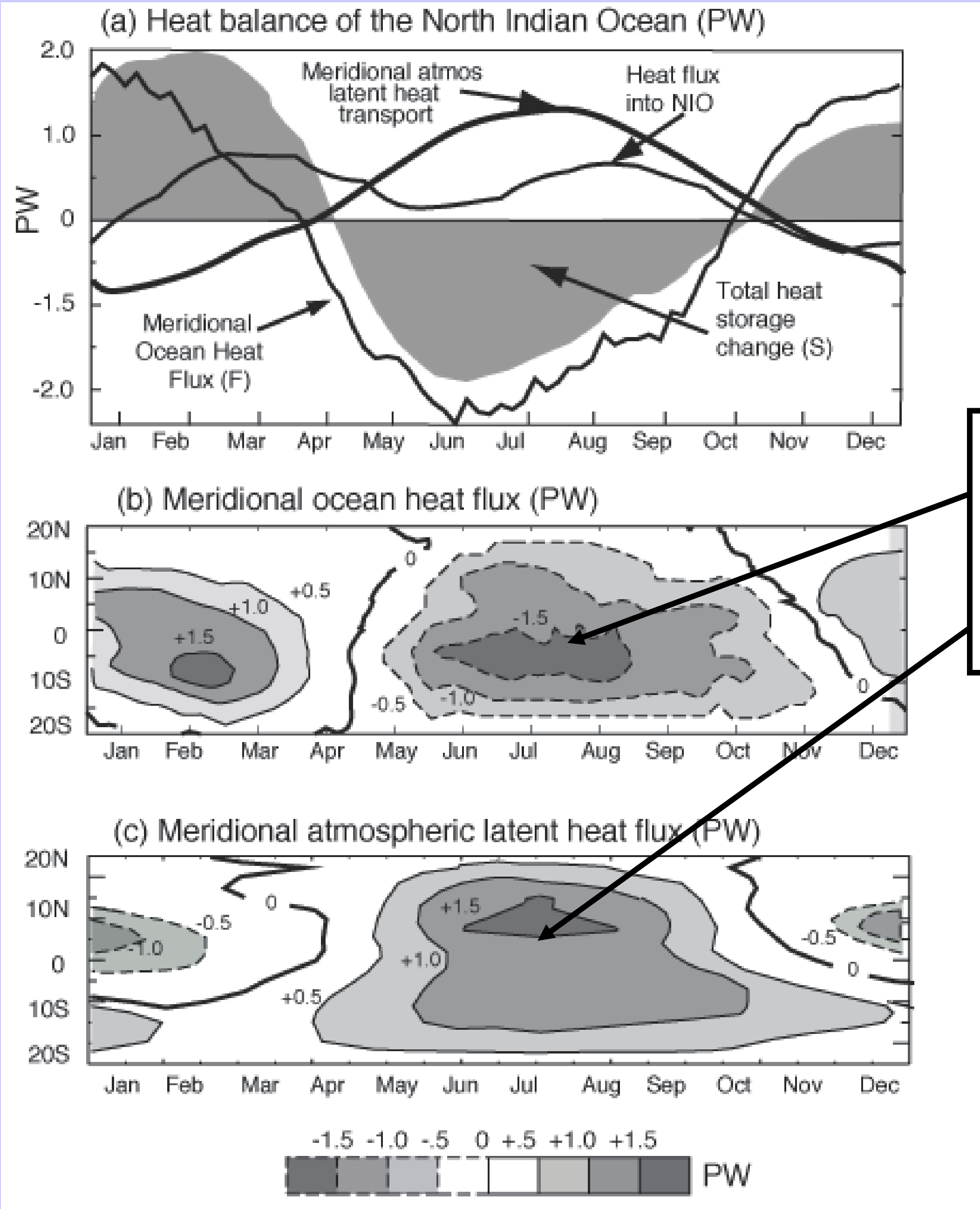
Self regulation

Annual Cycle of North Indian Ocean and Latent Heat Flux



Notice that max transport in summer hemispheres where ISO variance strongest

Self regulation by fluxing heat in opposite send in O and A

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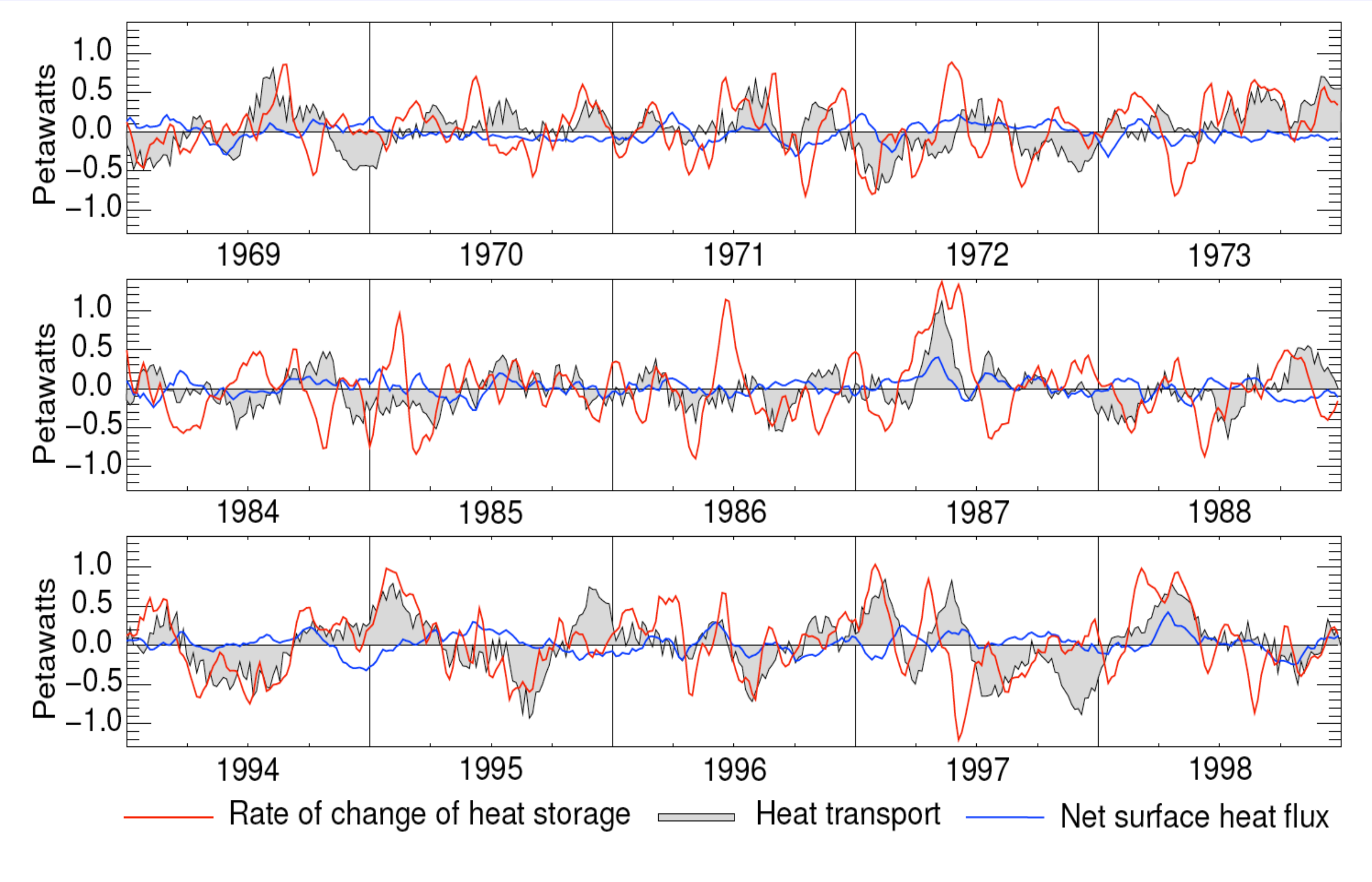
The “self-regulation” operates on a seasonal basis but also interannually.

If anomalous monsoon LH occurs (e.g., Large SST anom), monsoon winds are increased but so is Ekman transport in opposite direction thus cooling anomalous region

Probably why interannual variability of monsoon small

But, if we look more closely, most of the oceanic heat flux occurs in conjunction with active ISO periods



Reduced monsoon (pre-ISO)   Enhanced Monsoon

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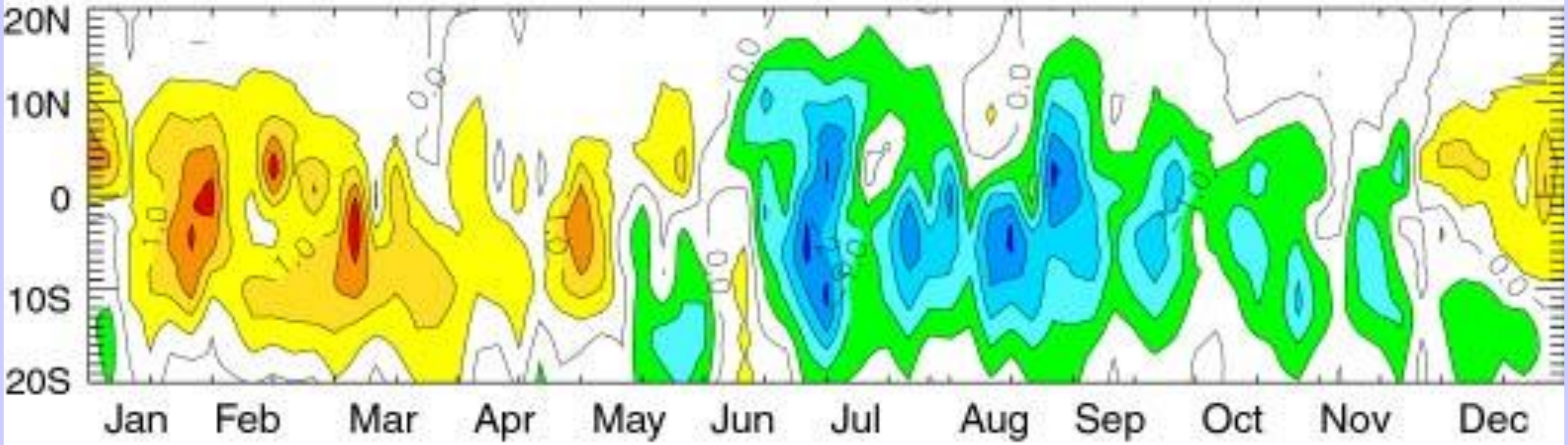
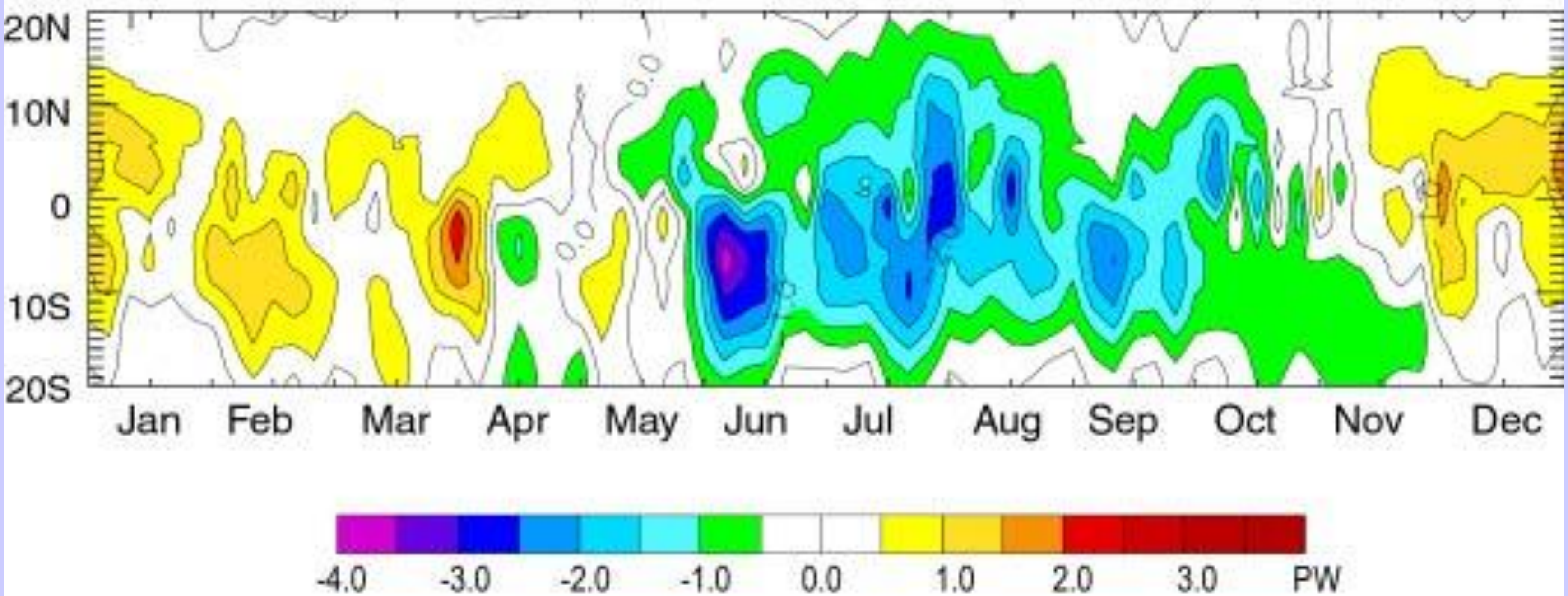
(c) Zonally averaged ocean heat transport 1987



(d) Zonally averaged ocean heat transport 1988



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Reduced Ekman | **Enhanced Ekman**

Reduced heat transport | **Enhanced transport**

Warming | **Cooling**

QuickTime™ and a
decompressor

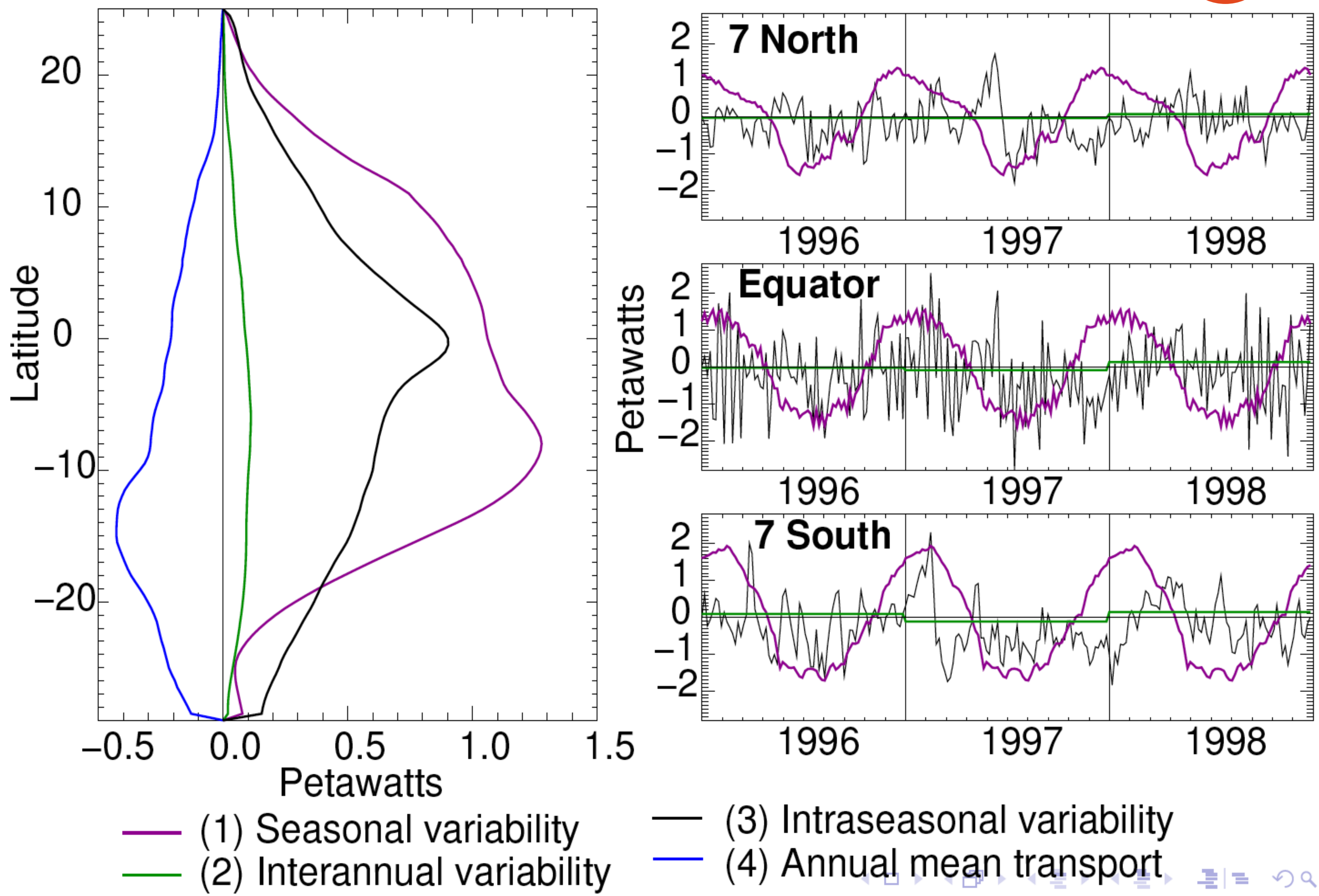
QuickTime™ and a
decompressor

Hypothesis

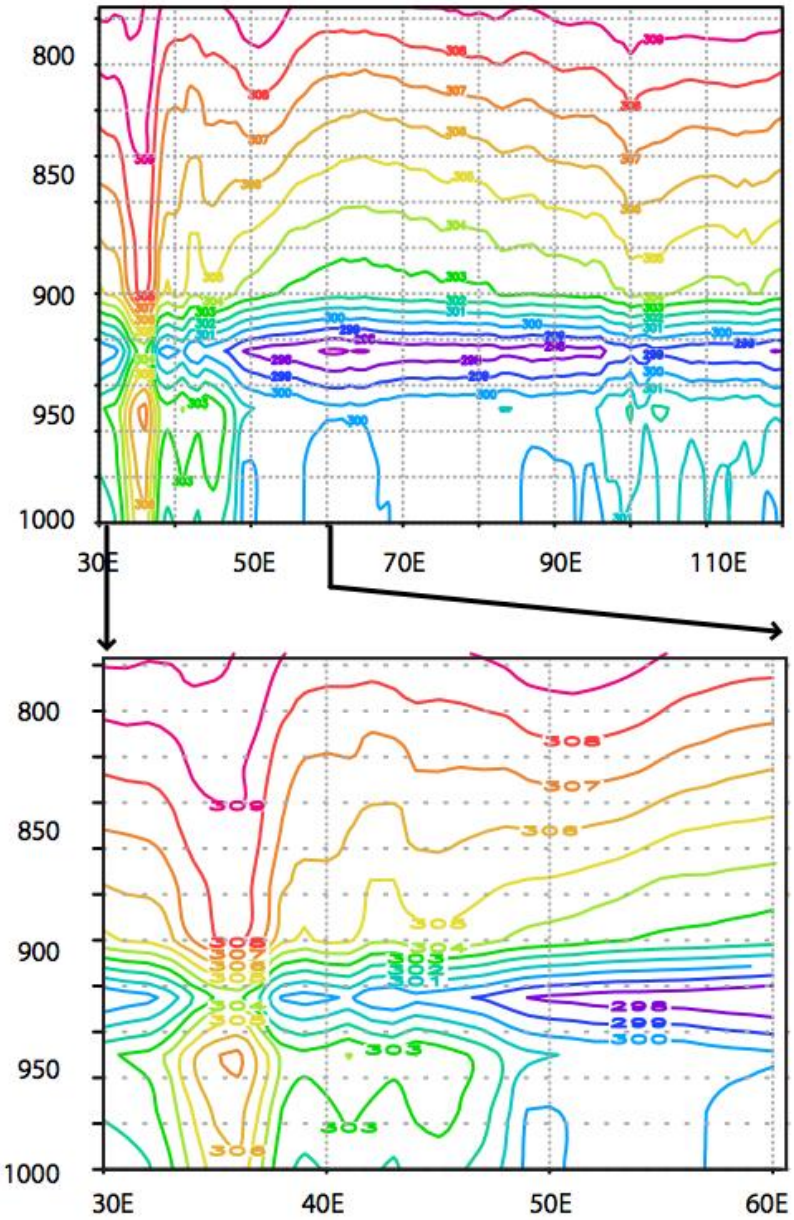
- ISO in Indian Ocean is a response to enhanced Cross-equatorial SST gradient
- Winds accelerate as LH flux increases but this acceleration accomplishes an enhanced southward ocean heat flux that cools the north Indian ocean.
- Time scale is regulated by the time to reestablish the SST gradient
- In this manner, the ISO acts in the same manner as the regulated seasonal and interannual monsoon
- In effect, the ocean-atmosphere system is showing remarkable “self-similarity” (common behavior on many time scales)
- From this, the ISo may be thought of as an instability of the coupled ocean-land-atmosphere system

Heat Transport Variability at Different Time Scales

4



Thermodynamical stability of the IO



WIO is a region of extreme subsidence with a well mixed boundary layer capped by a 4-5 K θ cap (I.e., $\delta\theta$=4-5K)

QuickTime™ and a decompressor are needed to see this picture.

Some thoughts on the coupled nature of the MJO in the Indian Ocean

- This is work iswith a former student. So far we have written up the first paper (*Chirikova, G. and P. J. Webster, 2006: Interannual variability of Indian Ocean heat transport. J. Climate, 19 (6), 1013/1031,* available at my web site). The second paper deals with the coupled nature of the MJO and is in early draft form. Some of these results have been shown here.
- Earlier studies (e.g., *Loschnigg, J. and P. J. Webster, 2000: A coupled ocean-atmosphere system of SST regulation for the Indian Ocean. J. Clim., 13, 3342-3360*) showed that there was a +/- 2PW annual cycle in Indian Ocean. Note that there is a net cross-equatorial annual southward flux of heat at 0.1PW. These ideas seem to work on the interannual and may also wok on intraseasonal

Some papers

Webster P. J. and C. Hoyos, 2004: Forecasting monsoon rain fall and river discharge variability on 20-25 day time scales.. *Bull. Amer. Meteor. Soc.* , 85 (11), 1745-1765.

Stephens, G. L., P. J. Webster, R. H. Johnson et al, 2004: Observational evidence for the mutual regulation of the tropical hydological cycle and tropical sea surface temperature. *J. Climate:* 17(11), 2213–2224.

Wang, B., P. J. Webster and H. Teng, 2005: Antecedents and Perpetuation of the Active-Break Indian Monsoon Cycles. *Geophys.Res. Lettrs*.

Agudelo, P. A., J. A. Curry, C. D. Hoyos, P. J. Webster, 2005: Transition between suppressed and active phases of convection in the Indo-Pacific warm pool intraseasonal oscillations (Submitted to *J. Clim.* May 2005)

Kim, H-M, C. Hoyos, P. J. Webster, I-S Kang 2007: Sensitivity of MJO sensitivity and predictability to sea-surface temperature: Analysis of an AGCM. To be submitted to J. Atmos. Sci.

Wang B, Webster P, Kikuchi K, Yasunari T, Qi Y, 2006: Boreal summer quasi-monthly oscillation in the global tropics, Clim. Dyn. 27, 661-675

Hoyos, C. and P. J. Webster 2007: Nature of monsoon precipitation. In Press, J. Clim.